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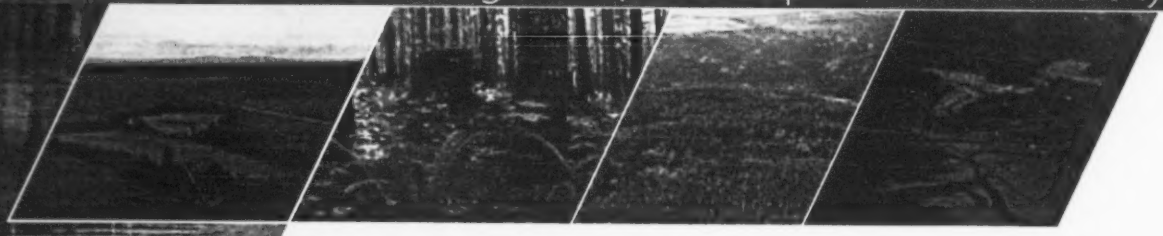
Mountain pine beetle: A synthesis of the ecological consequences of large-scale disturbances on sustainable forest management, with emphasis on biodiversity



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Mountain pine beetle: A synthesis of the ecological consequences of large-scale disturbances on sustainable forest management, with emphasis on biodiversity

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Abstract

This document provides a synthesis of recently completed studies to assess the ecological consequences of forest management after attack by mountain pine beetle or other large-scale disturbances. Studies are assessed for their contributions to gaps in knowledge previously identified in the Mountain Pine Beetle Initiative Working Paper "Evaluating effects of large scale salvage logging for mountain pine beetle on terrestrial and aquatic vertebrates," which was published in 2004. This report focuses on studies developed through the federal Mountain Pine Beetle Initiative, the federal Mountain Pine Beetle Program, and the complementary BC Forest Science Program. Relevant information from other jurisdictions is sometimes included to augment those studies. Topics examined are: the impacts of beetle kill and salvage operations on habitat attributes; the impacts of beetle kill and salvage operations on attendant processes, such as snag fall rates, light interception, and snow accumulation; and the wildlife response to large-scale beetle outbreaks and management strategies. For each of these three topics, we provide a summary of: research to date; pertinent findings to date; and gaps in research.

Keywords: mountain pine beetle impacts, salvage logging, Mountain Pine Beetle Initiative, Mountain Pine Beetle Program

Résumé

Nous présentons une synthèse des études récentes sur les conséquences écologiques de l'aménagement forestier consécutif aux infestations de dendroctone du pin ponderosa et aux autres perturbations de grande envergure. Nous évaluons dans quelle mesure ces études permettent de combler les lacunes existant dans les connaissances selon le document de travail Evaluating effects of large scale salvage logging for mountain pine beetle on terrestrial and aquatic vertebrates, publié en 2004 dans le cadre de l'Initiative sur le dendroctone du pin ponderosa. Nous évaluons en particulier les études menées dans le cadre de cette initiative fédérale, du Programme sur le dendroctone du pin ponderosa, également fédéral, ainsi que d'un programme complémentaire de la Colombie-Britannique, le Forest Science Program. Afin de compléter ces études, nous avons inclus dans certains cas l'information pertinente provenant d'autres provinces ou États. Les sujets suivants sont abordés : impact de la mortalité due au dendroctone et des coupes de récupération sur les caractéristiques du milieu; impact de la mortalité due au dendroctone et des coupes de récupération sur les processus connexes tels que la chute des chicots, l'interception de la lumière et l'accumulation de neige; réaction des espèces sauvages aux grandes infestations de dendroctone et aux stratégies de lutte. Dans le cas de chacun des trois sujets, nous présentons un sommaire des recherches menées jusqu'à présent, des résultats obtenus et des lacunes existant encore dans les connaissances.

Mots clés : impact du dendroctone du pin ponderosa, coupe de récupération, Initiative sur le dendroctone du pin ponderosa, Programme sur le dendroctone du pin ponderosa

Executive Summary

This document provides a synthesis of recent studies to assess the ecological consequences of post-mountain pine beetle (MPB) management and large-scale disturbances. Emphasis is placed on knowledge gaps identified in the Working Paper entitled "Evaluating effects of large scale salvage logging for mountain pine beetle on terrestrial and aquatic vertebrates" (Bunnell et al. 2004). More than 200 reports were reviewed; most were annotated (section 8).

Four topics are addressed:

1. The impacts of beetle kill and salvage operations on habitat attributes.
2. The impacts of beetle kill and salvage operations on attendant processes, such as snag fall rates, light interception and snow accumulation.
3. The direct wildlife response to large-scale beetle outbreaks and management strategies.
4. The potential impacts of alternative management strategies on maintaining biodiversity.

Each topic has its own section (Sections 2–4), where we summarize:

1. The research to date.
2. The pertinent findings to date.
3. Gaps in research.

Supportive detail is provided in the annotated list in Section 8.

Sections 5, 6, and 7 summarize findings across the major topics.

Section 5 summarizes potential impacts of alternative management strategies to sustain biodiversity. Climate change models strongly indicate that significant beetle infestation is here to stay, emphasizing the importance of developing management strategies and practices to mitigate effects of infestation.

Bunnell et al's (2004) observations and recommendations to help maintain biodiversity are reviewed in light of new findings to evaluate their validity, and whether additional approaches should be considered. Most of their recommendations regarding forestry planning and practice are confirmed. In Section 5 we summarize 16 recommendations regarding forest planning and practice in response to beetle kill. Based on new findings, four recommendations appear especially critical:

1. Do not salvage within 10 m of even small streams (e.g., S4).
2. Retain tree species other than lodgepole pine.
3. Avoid salvage logging in areas where intermixed pine represents < 40% of the species mix.
4. Plan areas to be reserved from harvest and areas to be harvested as large blocks.

Section 6 offers a summary statement of major research gaps and success in addressing key issues. The Mountain Pine Beetle Initiative addressed a diverse array of topics well and provided a broad base of new knowledge directly relevant to responding to the MPB (sections 4 and 8). Some questions cannot be answered completely yet because it is still too early for the full impact to appear; some questions raised by Bunnell et al. (2004) were multifaceted and difficult to address completely (nature is simply too complex).

Bunnell et al. (2004) and Safranyik and Wilson (2006) raised 11 questions concerning regeneration and other habitat elements in stands important to sustaining biodiversity. Few were wholly addressed by studies reviewed here (section 6.1). Two questions concerning regeneration remain critical:

1. Can sites requiring vegetation management be clearly defined?
2. Can prescribed fire mitigate hazard in unsalvaged stands?

The first is significant because some studies document a rapid understorey response to beetle attack; the second because of the uncertainty surrounding the future of unsalvaged stands. The first is easier to evaluate by local experience than by broader study.

Most of the remaining nine questions relate to the amount and distribution of stand structure elements critical to sustaining biodiversity. A review focused on studies that treat the topics likely could extract pertinent relationships between stand structure and biodiversity or organize data well enough to focus questions and rank their importance. At present, there is no firm documentation of the degree to which most structures are retained after beetle attack or salvage logging, but some assessments suggest they could be lacking over large areas (FPB 2009).

Bunnell et al. (2004) raised three broad questions regarding processes (section 6.2). All were at least partly addressed, and one (snag fall rates) is adequately addressed. The most critical area of uncertainty among processes is likely rates of stream flow:

- Alila et al. (2009) make a compelling case that many current findings regarding stream hydrography derive from misleading analyses. Given the uncertainty and the potential impacts, investment in re-analysis appears worthwhile.

Studies of direct effects on forest-dwelling organisms focused on caribou (designated "at risk" in the province) and, less completely, birds (section 6.3). We recommend that three areas of uncertainty be addressed.

1. Forest structures resulting from practices in beetle-attacked areas and impacts of these structures on vertebrates. Data from reports and peer-reviewed literature could be synthesized to document the changes. We rank it highly because it could guide subsequent studies effectively.
2. Whether stubbing or leaving tall stumps during salvage operations helps sustain cavity nesters. Data from forest types not dominated by lodgepole pine suggest it should, but the process bears additional economic costs and should be evaluated before being adopted or rejected in areas suffering beetle attack.
3. The minimum size of retention patches required to maintain healthy bryophyte and lichen populations. The single study conducted to date suggested most patches in salvage-logged stands were too small to sustain them. Broadening the study of typical post-salvage retention and responses of non-vascular plants would help assess whether current practices have major impacts.

Response of two caribou herds to initial phases of beetle attack were found to differ. The possibility of extending current studies presents a dilemma: although it likely would document probable causes of the near-term response, most beetle-killed trees will take years to become coarse woody debris and large accumulations of debris could impede caribou access to terrestrial lichens, yielding different long-term responses. Waiting 10 years, however, may miss critical features that could be ameliorated if understood.

Section 7 provides a summary statement on appropriate monitoring approaches. To evaluate the potential impacts of beetle attack and subsequent salvage operations on biodiversity, Bunnell et al. (2004) suggested a framework of three main indicators and associated key questions. Because there was no experience of a beetle attack of this magnitude, the framework was based on first principles. It is summarized in Section 7, where it is updated and refined based on findings of this review.

The importance of eight of the nine questions is affirmed by review; one is equivocal (caribou response) primarily because the full impact of beetle attack has not yet occurred. Questions addressed least well are those relating stand structure to organisms present. More detailed review could help to derive informative sub-indicators for specific Defined Forest Areas.

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1. Objective and Scope

This document provides a synthesis of recently completed studies to assess the ecological consequences of forest management after attack by MPB or other large-scale disturbances. Studies are assessed for their contributions to gaps in knowledge identified in the Mountain Pine Beetle Working Paper "Evaluating effects of large scale salvage logging for MPB on terrestrial and aquatic vertebrates" (Bunnell et al. 2004). This report focuses on studies developed through the federal Mountain Pine Beetle Initiative, the federal Mountain Pine Beetle Program, and the complementary BC Forest Science Program. Relevant information from other jurisdictions is sometimes included to augment those studies.

Topics examined are:

- The impacts of beetle kill and salvage operations on habitat attributes.
- The impacts of beetle kill and salvage operations on attendant processes, such as snag fall rates, light interception, and snow accumulation.
- The wildlife response to large-scale beetle outbreaks and management strategies.

For each of these three topics, we provide a summary of:

- Research to date
- Pertinent findings to date
- Gaps in research

The report provides summary statements first, with the supportive detail at the end. Topics are subdivided; for example, Section 3 "Processes" includes snag fall rates, canopy loss in pine snags, and light (radiation) interception. "Findings to date" and "Gaps in research" are noted under subheadings. Final sections collect findings derived from review of the major topics: Section 5 summarizes potential impacts of alternative management strategies to sustain biodiversity; Section 6 offers a summary statement of major research gaps; Section 7 provides a summary statement on appropriate monitoring approaches; and Section 8 provides an annotated list of projects addressing individual topics and their gains in knowledge. Overall advances by each project are combined by topic in the summary statement, "Pertinent findings to date," leading each topic in Sections 2–4. Note that when a project contributes to more than one topic, its detailed annotations are referenced by section number (e.g., section 8.2.4).

Treating any broad topic separately slices through connections within nature. We have tried to note linkages among topics. Each topic and its subdivisions are briefly described and pertinent findings and research or knowledge gaps noted. We begin each topic by noting the questions raised by Bunnell et al. (2004).

2. Habitat Attributes

Mountain pine beetle attack and subsequent salvage operations influence all major habitat attributes. Bunnell et al. (2004) noted that during salvage, "Positive effects potentially could be attained by making the amount of early seral stage more hospitable, increasing shrub cover and increasing amounts of larger downed wood. Predominantly negative effects can result from practices with regard to riparian habitat, deciduous stands, cavity sites, and older seral stages." Their observations and recommendations about practice that addressed key habitat attributes are summarized and evaluated in Section 5, and Section 6.1 includes the five questions they pose that would inform likely responses of biodiversity.

Of the 64 stand structure studies we reviewed (Canadian Forestry Service [CFS] and the BC Forest Science Program [FSP], from 2004 to present), 37 focused on describing secondary structure to estimate existing regeneration that may contribute to mid-term timber supply. Eleven examined stand structure after beetle attack or after salvage logging for its general value as habitat, 12 quantified stand structures as they relate to various organisms, and four related stand structure to risk of beetle attack. Studies describing stand structure overlap considerably with those related to process (e.g., fall rates of snags; effects of practices in riparian zones, section 3) or concerning species (e.g., stand structures conducive to maintaining caribou winter range, section 4). Our summary of findings presented here and the annotations of Section 8.1 are grouped by: advanced regeneration and establishment of trees, habitat elements in patches and retention, structure for specific organisms, and stand structure related to risk of beetle attack.

2.1 Advanced Regeneration and Establishment

Studies examining advanced regeneration and establishment of new trees after beetle attack and harvesting cover all the Biogeoclimatic Ecosystem Classification (BEC) zones affected by MPB and include many regions of the province. Most studies

address the current beetle outbreak, but some look at stand recovery after previous attacks. Coates (2008) described historical beetle attacks in the Flathead, and others (e.g., FPB 2007a; Astrup et al. 2008; Alfaro 2009) examined historical attacks in north and central BC. Most studies on regeneration and establishment occur in the Sub-Boreal Spruce (SBS) BEC zone, as it was the first area to be attacked and the hardest hit.

2.1.1 Pertinent Findings to Date

Both Bunnell et al.'s (2004) and Safranyik and Wilson's (2006) reviews raised questions about the nature of existing regeneration and establishment of new trees in beetle-attacked and salvaged stands. Considerable research has addressed the topic.

Regeneration varies greatly across locations and does not seem to be well predicted by site conditions (soil, stand age, proximity of non-pine seed sources). Generally, mixed stands have enough abundance of other species to add to the mid-term timber supply, provided they are not harvested during salvage (many studies, see section 8.1.1). Even stands mapped as "lodgepole pine-leading" often have a considerable mix of other species.

Most BECs show considerable release of both overstorey and understorey after beetle attack. Although for about 10 years after attack, light is too low for lodgepole pine to grow well in the understorey, other understorey trees and overstorey pine release well, often dramatically. Successful establishment of lodgepole pine, interior spruce, and subalpine fir regeneration begins about 4 years after beetle attack. In very moist rich areas, herb and shrub competition after beetle attack may reduce understorey tree responses (e.g., Hawkins and Rakochy 2007); release appears better in drier SBS variants than moister ones. Some stand types recover and become merchantable within 50 years (the *Mixed Pine–Spruce* and *Spruce Minor Pine* types). In some types, the advance regeneration is mostly pine and takes longer to release because of greater light requirements. Responses of understorey trees to light are well documented, especially in the SBS (see Huggard 2008a in section 8.1, Huggard 2008b in section 8.2, and summary in Kremsater et al. 2009). Some stocked stands will become mixed deciduous stands (Hawkins 2008).

Fertilization may encourage regeneration on some sites, but may be detrimental on others (e.g., Brockley 2006).

Only a few studies look at effects of beetle on other (non-lodgepole) pine species. Whitebark pine is extensively attacked (Jackson and Campbell 2009a,b). Effects of beetle on ponderosa pine ecosystems is under study (Vyse 2009). Connectivity of susceptibility Jack pine stands has been examined (Shore et al. 2009).

These findings suggest it is prudent to carefully harvest mature stands, leaving all mature non-pine species and as many saplings as possible. As well as providing mid-term timber supply, trees that persist after beetle attack provide important habitat elements that affect ecosystem processes (see section 3) and offer wildlife habitat (see section 4). Annotated findings are found in section 8.1.1.

2.1.2 Gaps in Research

Regeneration patterns are best known in the SBS zone. Despite generalities noted above, the ability to predict species mixes and amounts of existing regeneration is limited at best; large, unpredictable variation from location to location is typical. Relationships of light and site conditions to release of understorey regeneration are much better documented in the SBS zone, where patterns of release seem to be more predictable, than elsewhere.

2.2 Patches and Retention of Habitat Elements

Few studies focus on the nature of patches and the retention of habitat elements after beetle attack and salvage. Some studies document live trees, snags, and down wood in post-beetle stands. There is little work specifically on habitat elements (snags, down wood, shrubs) unless they relate to studies of certain species (see section 2.3). An exception is that fall rates of snags has been explored in depth (see section 3.1).

2.2.1 Pertinent Findings to Date

Studies suggest that MPB attack creates a pulse of snags and subsequent down wood. Increased light penetrating the dead canopy increases abundance of shrubs and herbs.

As noted in section 3.1 and section 3.2, the beetle adds to the detritus cycle in several pulses: soon after attack when needles fall, within 10 years as bark sloughs off, and within 15 years when most dead trees have fallen. By 25 years, most, if not all, of the beetle-induced mortality (80% on average) has passed through the snag stage to the CWD stage. An exception to this pattern was found by the Forest Practices Board (2007a), who noted 50% of dead trees were still standing 25 years after attack. A few studies (e.g., Hawkes et al. 2005) note that the models (Prognosis and to some extent Sortie) used to project forest growth do not

adequately project tree mortality—predictions of snags and down wood do not consider ongoing insect attack. Post-beetle levels of down wood are highly variable (e.g., FPB 2007a; Dykstra and Braumandl 2006; Hawkes et al. 2003, 2005). Klenner's (2009a,b) landscape study notes that salvage will decrease snags, down wood, and live trees important as ecological legacies at the stand level, so operational planning should consider both their amount and location.

Beetle increases understorey abundance and sometimes diversity, especially on moister sites. Although not documented in the studies we reviewed, other studies (see summary in Kremsater et al. 2009) note dramatic increases in pine grass cover and anecdotal alder responses. Youds (2009) has initiated a study on understorey dynamics.

Most studies investigating snags, down wood, and understorey are in lodegpole pine-dominated stands, usually in the SBS or Montane Spruce (MS). Vyse (2009) plans to examine beetle impacts on stand structures in ponderosa pine stands.

Stand structure after beetle attack differs greatly from the structure after salvage logging. The FPB (2009) evaluated retention after salvage logging and noted that although retention in recent cutblocks was increased in accord with the Chief Forester's guidance, lack of landscape-level planning allowed blocks to merge with older blocks to create very large harvested openings with little retention. They also noted that records of areas retained and areas harvested were inconsistent and incomplete, often indicating that there was more retention and less harvesting than had actually occurred.

Some studies evaluated more peripheral effects of salvage logging on stand structures. For example, Brown et al. (2008) looked at carbon balance and noted that clearcut salvage harvesting can result in a site being a carbon source for at least 10 years. Thus, the increase in the Allowable Annual Cut (AAC) in response to the beetle attack will likely significantly reduce the ability of BC's forests to sequester carbon.

Welham and Seely's (2007) study suggests managing soil organic matter with care on sites with more shallow soil depths and less organic matter. Ways of remotely viewing/documenting the extent of soil disturbance are explored in Dubé et al. (2006). Annotated findings are found in section 8.1.2.

2.2.2 Gaps in Research

The character of retention patches in salvage logged areas is poorly documented (FPB 2009). Even basic information on amounts of retention is often lacking. Information on the quality or character of retention is even weaker. Legacies in unharvested beetle attacked stands are not generally known, but are documented in a few locations (e.g., FPB 2007a; Dykstra and Braumandl 2006; Hawkes et al. 2003, 2005). Structures and down wood that remain after salvage logging are also not documented. Snag creation and fall due to beetles have been modelled and are well known for lodgeople pine, but less data exists for ponderosa and other pines (Huggard and Kremsater 2007 in section 8.2.1). Understorey responses after beetle attack (other than responses of regenerating trees) are seldom documented; Youds (2009) has a study beginning on understorey dynamics (see section 8.1.3).

2.3 Studies Examining Stand Structure as Habitat for Organisms

These include several studies on birds, two on small mammals, several on habitat for caribou, one on cryptogams, and a few on effects of beetle on other insects. Section 4 examines these studies for information regarding responses of organisms to beetles; here, we report information these studies provide on stand structures.

2.3.1 Pertinent Findings to Date

Some studies established stand structure plots to acquire information related to their species of interest (e.g., Martin et al. 2006; Chan-McLeod et al. 2008; Norris and Martin 2008 for birds). Several caribou projects (e.g., Williston and Cichowski 2006; Cichowski 2007; Seip and Jones 2009; Youds 2009) collected quite detailed stand information. Williston and Cichowski (2006), for example, collected information on soil characteristics, humus, down wood, moisture regime, vegetation cover, conifer regeneration, cones, windthrow, lichen/moss kinnickinick twinflower cover, arboreal lichens, and light availability. They reported post-beetle reduction of lichens and increases in kinnickinick, red-stemmed feathermoss and twinflower. One study on caribou habitat indicated that small openings in the Sub-Boreal Pine Spruce, very dry, cold SBPSxc are likely to become naturally regenerated by lodgepole pine (Waterhouse 2008).

Lewis (2008) summarized existing literature to document expected responses of some small mammals to stand structures post beetle. The summary provides information on likely stand densities and canopy closures after beetle attack. In beetle-affected forests, abundance of canopy-dependent small mammals is expected to decline less in unsalvaged than in salvage-logged stands. In contrast, species such as chipmunk and deer mice are expected to thrive under both conditions. Sullivan (2008)

also evaluated small mammals in different post-beetle environments, but the executive summary (all that is available to date) provides little information on stand characteristics.

Nealis (2007) and Noseworthy (2008) examined whether beetle-induced changes in stand structure increase stand susceptibility to western spruce budworm. Both studies provide basic descriptions of post-beetle stand structures.

Botting and Delong (2008) documented the diversity and abundance of lichens, bryophytes, and liverworts on downed wood of different decay class and species in retention patches left after beetle attack and in the logged matrix. The retention patches were too small to prevent loss of species over time. Recent down pine had low species abundance, indicating that mixed stands with a range of ages of down wood are important for many cryptogams. Their raw data would likely provide information on levels of down wood in retention patches and harvested matrix.

Aukema and Klingenberg (2007) are exploring whether attack by Warren's root collar weevil is influenced by pine beetle attack. They are searching for ways to explain shifts in weevil attack after pine beetle and attempting to relate that to stand structure, but no solid results are reported yet for either stand structure or weevil patterns.

Annotated findings are found in section 8.1.3.

2.3.2 Gaps in Research

Researchers studying organisms often collect stand structure data to relate their organisms to various stand characteristics. Such studies usually do not report an overall description of the habitat elements retained in the harvested blocks or retention patches, but nevertheless the researchers likely have such data that could be used to create broader summaries.

2.4 Stand Structure and Resilience to Beetle Attack

Of studies that evaluate types of stand conditions that may provide protection from beetle attack, some document the spread of beetles into young pine and others evaluate stand treatments to reduce risk of attack.

2.4.1 Pertinent Findings to Date

Effects of post-thinning density on susceptibility of mature lodgepole pine to beetle attack vary with beetle population levels. Thinning can offer some protection when beetle pressure is low, both at low stand density (because open stands have a less desirable microclimate) and at high stand density (because dense stands have smaller diameter trees which are less desirable to beetles). Conversely, increasing tree growth and vigour by thinning may increase the risk of beetle attack when beetle populations are high. Under these conditions, the mitigating effects of microclimate are probably minimal, and the risk of attack may be inversely related to residual stand density (largely as a function of diameter at breast height, or DBH).

For young stands, geographic location rather than its ecosystem currently appears to drive the incidence of MPB. In younger stands, MPB prefers well-spaced, larger stems. Annotated findings are found in section 8.1.4.

2.4.2 Gaps in Research

More reports may look at "beetle-proofing," but that was not the focus of this review. The papers noted here and in section 8.1.4 indicate that studies of beetle-proofing and spread of beetles often report on stand structure post-thinning treatment, but usually such structure is recorded in terms of live stems and dead stems without documenting other habitat elements.

3. Processes

Mountain pine beetle attack and subsequent salvage operations likely influence every identifiable process within individual stands and over larger areas. Processes do not exist separately; we tease them out of nature to document and interpret them. Although separating processes can sever closely connected issues, it is useful because we combine different processes to answer different questions. Bunnell et al. (2004) recognized that forest death and removal have significant impacts on forest hydrology that incorporate many processes, including changes in forest canopy, precipitation interception, evapotranspiration, local meteorology, and snow accumulation and ablation. They noted that the increased rate of cut and the nature of salvage operations could influence each of these processes, and posed three broad questions about biodiversity (see section 6.2 of Knowledge Gaps, summary statement).

In our review, we recognized several processes, none wholly discrete. Two significant areas of study are aggregates of processes: hydrology and climate change. The list below ranks processes approximately by primacy of effect. For example, snag fall rates and canopy loss in pine snags influence light and snow interception. Processes treated are:

1. Snag fall rates
2. Windthrow
3. Canopy loss in pine snags
4. Light (radiation) interception
5. Hydrology (includes snow interception, accumulation and ablation)
6. Climate change

3.1 Snag Fall Rates

Rates of snag fall (together with decay) determine the duration of suitable habitat for cavity-nesting species, rates of provision of down wood, and the degree to which standing dead canopy intercepts light and snow.

3.1.1 Pertinent Findings to Date

Huggard (2008c), summarizing and extending the synthesis of Huggard and Kremsater (2007), included eight studies in its synthesis. The compilation is more extensive than that of Lewis and Hartley (2005); it does not include data of Lewis and Thompson (2009), though the very low rates of fall of lodgepole pine snags they report within the first 5 years of death are within the range summarized by Huggard (2008c). Huggard found high variability among the different studies, with a fivefold difference in annual rates during the period 5 to 5 years after tree death. Despite factoring out effects of snag size, variability remains from site effects (warmer, wetter sites tend to have higher fall rates) and random events like storm winds. Variability among studies produces wide confidence intervals in the bootstrapped results. Waterhouse (2008), looking at tree fall in caribou winter ranges, reported fall rates of live and dead trees combined ranging from 1.7% to 3.8% per year and noted those rates did not differ between shelterwood and group selection harvest systems. She expected the rate to increase and perhaps cause problems for caribou. Annotated findings are found in sections 8.2.1 and 8.1.3 for studies addressing wildlife.

3.1.2 Gaps in Research

No major gaps. More knowledge of local site effects would help local planning, but these are likely to remain highly variable.

3.2 Windthrow

Bunnell et al. (2004) observed that retained patches will have windthrow. Few studies report windthrow after beetle attack or from retention patches left after salvage logging. On the coast, Beese (2001) reported windthrow rates as high as 29% in dispersed retention at the Montane Alternative Silvicultural Systems (MASS) site south of Campbell River. We anticipate similar levels and patterns in the interior.

3.2.1 Pertinent Findings to Date

Chan-McLeod (2007) noted that, as in coastal studies without beetle attack (Beese 2001), rates of windthrow were higher under dispersed retention than in aggregated retention or unharvested controls. Beetle-killed older stands had the lowest rates of windthrow, but also had higher beetle mortality than the harvested stands. Waterhouse et al. (2008) noted "high" windfall rates when retention was low and dispersed uniformly through the block (again echoing coastal findings). Annotated findings are found in sections 8.1.3 and 8.2.1.

3.2.2 Gaps in Research

Although few studies report windthrow, the knowledge gaps are minor. Current studies estimate only rankings (not rates) and follow the ranking of retention effects in stands unaffected by the beetle. Estimates of snag fall rates of Huggard (2008b) incorporate windthrow. More knowledge of local site effects might help local planning, but these will likely remain highly variable.

3.3 Canopy Loss in Pine Snags

Canopy of standing snags affects snow and light interception and snow ablation. Dead trees contribute less canopy with time, as needles are lost, then fine branches, and eventually all branches.

3.3.1 Pertinent Findings to Date

Huggard (2008c) found several studies reporting that beetle-killed lodgepole pines lose all their needles by 3 to 5 years after death, and most of their branches by 10 to 15 years. Transition from class 3 to class 4 snags (Thomas et al. 1979 classification) occurred at 6.1 years (95% CI: 3.5–10.8 years) in a synthesis of four studies of five species of pine (data from Huggard and Kremsater 2007). This transition represents the loss of fine branches, which may provide about half of the tree's canopy cover. Transition from class 4 to class 5 occurred at 21.5 years (95% CI: 12.3–27.6 years), representing loss of all but short branch stubs. Annotated findings are found in sections 8.2.2 and 8.2.4.

3.3.2 Gaps in Research

No major gaps. More knowledge of local site effects would help local planning, but these are likely to remain highly variable.

3.4 Light Interception

Light interception by living and dead pine influences regeneration (this section), and snow interception and snow ablation (section 3.5).

3.4.1 Pertinent Findings to Date

Coates and Hall (2006) report that lodgepole pine snags intercept 47.4% less light at 8 to 17 years old than at 0 to 7 years. Astrup et al. (2008) and Astrup and Close (2008) also have studied light availability after beetle, but few results are yet presented (all annotated in section 8.1.1). Huggard (2008b) developed an approach working towards predicting the percent of above-canopy light reaching the ground over a whole stand as a function of time since tree death. He divided the problem into measurable components (fall rates of dead lodgepole, snag breakage, loss of foliage and branches) to produce an integration of stand-level light transmission over larger areas as a function of proportional tree reduction. The approach fits sparse empirical data well. He noted that understorey and non-pine species influence interception; first approximations to their effect are found in Huggard (2008c). Annotated findings are found in section 8.2.3. Some of the caribou–lichen related studies also measure light (Waterhouse et al. 2008; Williston and Cichowski 2006; see sections 8.1.2 and 8.1.3).

3.4.2 Gaps in Research

Huggard's (2008b) approach to predicting shading over time in beetle-affected stands is intended as a general approximation under different beetle management scenarios. It currently is unclear if more complex, explicit stand modelling better informs silvicultural decisions, such as selection and timing of underplanting stands. No modelling can replace direct experimental comparisons of light levels and seedling responses under beetle-affected canopies. Section 2.1 notes several studies providing information on light levels and regeneration in the SBS; a further few consider other BEC zones. Because light interception by foliage and branches heavily dominates the shading trajectories (Huggard 2008b), its effect is the most pressing research needed to understand light interception. Study should include living and dead trees plus the variability in the transmission of each snag class, and the ages of the snags in the classes.

3.5 Hydrology

Forest disturbance significantly affects forest hydrology due to its effects on the forest canopy that influence precipitation interception, evapotranspiration, local meteorology, and snow accumulation and melt (ablation). Road building and other effects of harvesting also influence stream characteristics. The extent of the current outbreak means these factors affect both stands and large areas.

3.5.1 Pertinent Findings to Date

Studies are of two forms: syntheses and local measurements. Several papers include both.

- Interception: Canopy of beetle-infested stands continues to provide significant interception of rain and snow through grey attack phase (Boon 2007, 2008; Teti 2008; Carlyle-Moses and Burles 2009; Cichowski 2009). Seip and Jones (2009), however, reported no difference in snow depth between attacked pine forest and clearcuts.
- Ablation: Little initial change in ablation in unlogged, beetle-killed stands (Boon 2008; Carlyle-Moses and Burles 2009). Salvage logging increases ablation rates (Teti 2008). See Alila (2006) for rates under intact canopies.
- "Scaling up" of meteorological measures from various sources (meteorological data for stands to the broader landscape) has met with mixed success: poor (Boon 2008), incomplete (Coops and Weiler 2008), and promising for ECA (Huggard

2008c) and numerical modelling (Alila 2008; Kuraś et al. 2008; Moore 2009). Numerical modelling requires detailed meteorological data; Boon's lack of success appears to be due to inadequate forest cover data.

- Large-scale hydrology models (e.g., the entire Fraser Basin) have been developed (Schnorbus et al. 2010; Weiler et al. 2009). At most scales, as the total area salvage logged increased, peak flows also increased and generated an associated increase in flood frequency—the larger the magnitude of a flood event, the more frequent it may become (Wei 2007a; Alila 2008; Kuraś et al. 2008). Kuraś et al. reported that roads mitigated effects of harvesting by transporting water out of the basin, but Alila (2008) considers these results incomplete. Peak flow regimes are largely tolerant of harvesting up to 30%, but effects past about 30% could induce significant changes. The threshold appears to be between 30 and 50% of the area harvested. Effects vary with watershed; Wei (2007a) found no long-term effects in large-scale harvest in the Bowron.
- In snowmelt-dominated streams, peak flow is much more sensitive to logging at higher elevations (Alila 2008).
- Large woody debris: in areas under beetle attack, more large woody debris is imported into stream channels, but effects are unclear. Using coarse woody debris budgets, Hassan et al. (2008) concluded that in the worst case scenario (100% mortality), input rates of woody debris from riparian areas with lodgepole pine would increase about 3.7 times over pre-infestation rates, increasing net storage in stream channels until about 2050. They concluded that on average, the predicted input of woody debris transferred following beetle infestation is about 10% of that derived from a stand-replacing event. They observed that the increase in woody debris storage resulting from lodgepole pine mortality was thus minor compared to the undisturbed range of wood debris dynamics. The effect may be larger: some parameters in the modelling methodology appear incorrect, leading to an underestimate (see annotation in section 8.2.4). Studying streams in Bowron 20 to 30 years after accelerated harvest activity, Nordin et al. (2008) found that the large woody debris indicator in Routine Riparian Effectiveness Evaluation (RREE) failed > 85% of the time because of too much debris induced by logging. They also reported that a regeneration time of 20 to 30 years after clearcutting was insufficient for riparian indicators to recover to pre-harvest conditions. Hassan et al. (2008) recognized that effects could be basin specific. Wei (2007b, 2009) provides the most direct measures of large woody debris (LWD) input and export. He found that wildfire and beetle infestation had large impacts on dynamics of LWD, channel morphology (changed stream channel characteristics), and input of litterfall. Beetle infestation increased needle mass and reproductive materials in streams. Export rates of LWD pieces were significantly less in beetle-attacked sites than in control sites, which will ultimately change channel morphology.
- Stream temperature: Mellina (2006) reported that at downslope sites affected by logging, the logged headwater and lake-headed streams were generally warmer with greater daily fluctuations than their forested counterparts. Logging occurred well prior to the beetle outbreak. Canopy cover was reduced by an average of ~ 31% in logged versus forested lake-headed streams, compared to reductions of only ~ 9% in logged versus forested headwater streams. Riparian zones of grey attack stands had higher shade values than harvested sites (Rex et al. 2009), which would reduce increases in stream temperature. There was no apparent effect on rainbow trout, but effects on bull trout are suggested.
- A survey of 56 streams (Hinch and Mellina 2008) found bull trout only in forested streams; sculpins and rainbow trout were found in recently logged streams.
- Descriptors of water quality showed little impact by the beetle other than an increase in turbidity associated with stream crossings during harvest (Brown et al. 2009). Hinch (2008) reported low levels of sedimentation in streams > 10 years post logging.
- Data relevant to calculating Equivalent Clearcut Area (ECA) have been collated from several sources and applied to the Kamloops area (Huggard 2008c). Huggard's approach is useful and could be applied to other areas. It is unclear whether the more detailed modelling of Alila (2008), Moore (2009), and Weiler et al. (2009) will eventually supplant ECA. These models require the influence of overstorey canopy which currently is approximated by ECA. Tests of the Distributed Hydrology Soil Vegetation Model (DHSVM) show it is broadly accurate but detailed data are required to use it effectively.

Specific findings are summarized by study in section 8.2.4.

3.5.2 Gaps in Research

The model of Mellina et al. (2002) appears usefully predictive for stream temperature (Mellina 2006). Measures of water quality (turbidity, sedimentation, and water chemistry) were addressed directly (Hinch 2008; Brown et al. 2009) and indirectly by RREE (e.g., Nordin et al. 2008; Rex et al. 2009). Long-term effects of the consequences of LWD resulting from salvage logging remain equivocal, but are more likely to be negative than positive. The equivocal nature of the findings is not a result of poor design, but of the time required for effects to appear and of high inter-basin variability. The ability to obtain more data-based and credible forecasts of effects of forest harvesting on stream hydrographs appears promising. Pros and cons to continued immediate investment are outlined in section 6.2.

Bunnell et al. (2004) raised the issue of whether streams flowing through unsalvaged lodgepole pine acquired undesirable characteristics. The dominant factor appears to be geology of the basin (Brown et al. 2009). Potential effects of input of coarse woody debris and shading (temperature) in unharvested streams have been evaluated (e.g., Rex et al. 2009; Wei 2009); no negative effects were documented. The flow of streams through salvaged areas remains the greater area of concern.

3.6 Climate Change

Climate change is not an "attendant process" influenced by bark beetle and salvage operations, but is briefly treated here because it affects all processes, including those modified by salvage logging. We have limited our review to two projects specifically addressing climate change and bark beetle response (Carroll et al. 2004; Aukema 2009).

3.6.1 Pertinent Findings to Date

Although an abundant supply of mature lodgepole pine has encouraged the beetle outbreak, its spread and failure to collapse is a product of global warming. There is no reason to expect collapse; rather, the outbreak is likely to spread through the boreal forest. Although never explicitly stated among the studies in this review, one consequence of the beetle's response to warming is that most processes under study are being evaluated in a warmer environment than ever previously documented.

3.6.2 Gaps in Research

The Mountain Pine Beetle Initiative has facilitated development of models useful in projecting the spread of the outbreak. Given the extent of the outbreak in BC, these models are now primarily useful when refined to accommodate jack pine (e.g., Shore et al. 2009) and applied nationally. When coupled with projected climate change effects on lodgepole distribution, the models might reveal refugia for lodgepole pine where natural genetic variation could be sustained.

4. Wildlife Response to Large-scale MPB Outbreaks and Management Strategies

Only terrestrial vertebrates are treated here; fish are considered under section 3.5 Hydrology; some insects are considered in section 2.3 (stand structure as habitat for organisms). Beetle attack and subsequent salvage operations influence all major habitat attributes and thus will influence resident wildlife. Bunnell et al. (2004) posited that appropriate planning of salvage could make early seral stage areas more hospitable, increasing shrub cover and increasing amounts of larger downed wood. They also noted that predominantly negative effects can result from practices with regard to riparian habitat, deciduous stands, cavity sites, and older seral stages. They observed effects of habitat structure and wildlife (section 6.1) and raised four broad questions with regard to terrestrial wildlife (see section 6.3 Knowledge gaps, summary statement). These questions have not yet been fully addressed. Studies to date emphasize birds and caribou.

4.1 Birds

Work on birds was largely limited to two areas, one atypical in its large proportion of aspen.

4.1.1 Pertinent Findings to Date

- Five years after beetle attack, the changes had a measurable effect on avian abundance: about 64% of bird species responded to the level of beetle infestation within the stand (Chan-McLeod et al. 2008). Response reflected the natural history of the species: those that declined with increasing levels of infestation were generally foliage gleaners such as Swainsons' thrush, warbling vireo, and western tanager, or of the mature forest guild, which prefers closed canopy habitats. In contrast, cavity nesters increased with intensity of beetle attack, probably in response to the increased supply of suitable nest sites in dead and dying trees.
- In comparisons of unsalvaged areas to various forest harvesting treatments after beetle attack, the most consistent and pronounced treatment effects were between unsalvaged controls and all other harvest treatments (Chan-McLeod et al. 2008). Species more abundant in controls included brown creeper, Cassin's vireo, golden-crowned kinglet, Hammond's flycatcher, red-breasted nuthatch, Swainson's thrush, and three-toed woodpecker. Retention had more effect than cutblock size. Regardless of cutblock size, birds usually found in mature forest used treatments with greater retention more often than treatments with less retention.
- Where aspen is abundant, studies indicate the richness of bird species and abundance is sustained or enhanced during initial stages of beetle attack (Stone 1995; Martin et al. 2006). As pine mortality increased, some species declined in

abundance. Martin et al. (2006) reported no decline in species richness in stands with up to 60% pine mortality; Stone (1995) found species richness declined when pine mortality exceeded 75%. The result is broadly "boom and bust" as species respond to abundant insects, then decline as forage declines.

- Density of red-attacked pines correlated positively to species richness of woodpeckers and negatively to richness of other forest birds (Drever et al. 2008). Where aspen was abundant, positive responses among cavity nesters to the beetle appear largely due to increased food resources, rather than to more snags (Norris and Martin 2008). Although they still respond to beetle density, black-backed woodpeckers are a potential exception that nest almost exclusively in conifers and seek appropriate conifer snags. Appropriate nest sites appear to be more important than beetle abundance (Bonnot 2006; Bonnot et al. 2008).
- Understorey gained in diversity and structural heterogeneity because of openings in the canopy, and favored bird species associated with understorey (Stone 1995).
- Bird species negatively affected by the beetle infestation include those associated with canopy foliage such as pine grosbeak and goshawk (Stone 1995; Chan-McLeod et al. 2008), and those who found their food sources reduced or inaccessible (northern flicker, red-naped sapsucker, olive-sided flycatcher, western wood-pewee, and yellow-rumped warbler; Martin et al. 2006). Given that the flicker forages primarily on ants on the ground, its decline may be associated with increased understorey and possibly debris.

Specific findings are summarized by study in sections 8.1.2, 8.1.3, and 8.3.1.

4.1.2 Gaps in Research

Birds are the richest group among vertebrates and best addressed, but studies lack data to guide forest practices. Three questions appear most informative to guide forest practice:

1. Which bird species are sustained in large areas of beetle kill?
2. Which bird species remain in non-pine and pine retention patches?
3. Do specific salvage practices sustain groups of species (e.g., stubbing and cavity nesters)?

The first two questions are addressed incompletely; the third not at all. Although about 50% of beetle-killed trees remain standing for 10 years (Huggard 2008b), it is unclear whether they incur rot quickly enough (Lewis and Thompson 2009) for stubbing to make an important contribution to nest sites. Because low snag densities support nesting, retaining snags or stubs could contribute, but that is undocumented and possibly moot—there may be large and well-distributed areas of beetle-kill with abundant snags that will not be harvested. However, FPB (2009) documents extensive tracts without adequate retention.

Martin et al. (2006) emphasized the large knowledge gap surrounding cumulative effects, particularly climate change, in predicting beetle impacts on wildlife populations. Currently, the only empirically based climate change model addressing vertebrate species in BC is that of Bunnell et al. (2010). It has not been applied to the issue of beetle infestation.

4.2 Mammals

Effects of large-scale MPB epidemics on mammal populations were assessed only for ungulates (primarily woodland caribou) and grizzly bear. One study in Utah (Stone 1995) examined small mammals; work in BC has been initiated by Sullivan (2008).

4.2.1 Pertinent Findings to Date

Small Mammals

- Beetle infestation outbreak enhanced abundance and species richness of small mammals (Stone 1995). Understorey gained in richness and structural heterogeneity because openings in the canopy favored some species (Stone 1995). Species such as red squirrel, a canopy species, responded negatively to tree mortality. Richness of small mammals was enhanced at intermediate levels of disturbance, but decreased in stands with highest levels of tree mortality, > 75% (Stone 1995).
- Based on review of literature on green tree retention and natural disturbance, Lewis (2008, sections 2.3 and 8.1.3) suggested a decline in abundance of canopy-dependent small mammals after beetle attack and a still greater decline if stands were salvage logged. In contrast, species such as chipmunk and deer mice were expected to thrive under both conditions.
- Sullivan (2008, sections 2.3 and 8.1.3) evaluated small mammals in different post-beetle environments in stands with retention of Douglas-fir (seed tree, group retention, uncut, and young). Red-backed voles had higher abundances in uncut forests; red squirrels were abundant in uncut and group retention forests. Northern flying squirrel and masked shrew abundance were similar among treatments.

Ungulates – Caribou

- Migration pattern and foraging habits of caribou were similar prior to and during the grey stage of beetle attack. Woodland caribou in central British Columbia continued to use dead pine forests (Cichowski 2009).
- Seip and Jones (2009) found that dead pines were not effective at intercepting snow, but yielded softer snow, which is easier to dig. Consequently, caribou foraged exclusively in the beetle-infested pine forest when snow depth exceeded 50 cm. Cichowski (2009) found that weather conditions in winter exerted a greater influence than snow conditions on caribou's foraging on terrestrial lichens; caribou dug craters in snowpacks up to 93 cm in open pine habitat (Cichowski 2009). Other studies found that dead pines do intercept snow (section 3.5.1).
- In winter, caribou used salvage and clearcut areas similarly. They used salvaged blocks, clearcuts, and dead pine forests an average 4%, 18%, and 77% of the time respectively (average 2007–2009; Seip and Jones 2009). Abundance of terrestrial lichen (Cladina spp.) was low in salvaged blocks and in dead pine forests where it had decreased by 11.5% (since 2006), apparently displaced by dwarf shrubs. Biomass of arboreal lichen in caribou feeding areas remained constant through the years (Seip and Jones 2009).
- Calf recruitment rate was low to moderate (Cichowski 2009).
- In the Fort St James area, uplifts in cut to accommodate salvage logging were projected to have little impact on amount of winter ranges (McNay et al. 2008). Impact of predation appears to increase with roads and early seral stands; e.g, salvage logging. Another model for the Tweedsmuir–Entiako caribou herd has not yet yielded results on salvage impacts (FSP 2008). Goward et al. (2008) have devised ways of scaling up abundance of hair lichen (Bryoria species) habitat; salvage was not directly addressed.
- Cichowski (2007) and Williston and Cichowski (2006) investigated lichen levels in caribou winter ranges and attempted to relate them to light, competition with other herbs or shrubs, and needle depth (see sections 2.3 and 8.1.3). The study is ongoing.

Other Ungulates

- In northern Utah, ungulate fecal pellet count correlated positively with percent tree mortality (Stone 1995). Results on habitat selection by moose in southeastern British Columbia were not conclusive (Munro et al. 2008). Deer used stands with a variety of canopy conditions (Sullivan 2008).

Grizzly Bear

- In southeast British Columbia, grizzly bear density increased during the first decade after the 1970 beetle attack when salvage logging was very active. But in the third decade, both reproduction and survival rates of grizzly bear cubs declined. Salvage logging is unlikely to have contributed to the decline; the subsequent decline of food sources with post-logging canopy closure (e.g., ungulates and huckleberries) was more likely responsible. Although salvage logging did not directly affect bear population trend, it likely had indirect impacts. Where road and access are created during salvage logging, chances of bear mortality due to human intervention increased (Munro et al. 2008).

4.2.2 Gaps in Research

Work on grizzlies was retrospective and inferential, but interpretations fit with known natural history. Prediction models built for caribou populations were hindered by many knowledge gaps, including processes (e.g., snag fall rate, stand recovery rate) and influence from trends of other species (e.g., predation rate, changes in vegetation, variations in terrestrial and arboreal lichens). Some of these gaps have been filled (e.g., snag fall rate), suggesting that modelling was premature. The greater barrier may be that the caribou herds are not responding similarly (compare Cichowski 2009 to Seip and Jones 2009). A persistent problem across mammal species is the lack of pre-outbreak data that would aid in interpreting post-outbreak surveys.

5. Potential Impacts of Alternative Management Strategies to Sustain Biodiversity

Climate change models strongly suggest that significant beetle infestation is here to stay. The beetle's persistence emphasizes the importance of developing management strategies and practices that can mitigate effects of infestation. Bunnell et al. (2004) offered observations and recommendations to help maintain biodiversity. Recommendations evaluated and updated by this review are:

- Retain tree species other than lodgepole pine, ideally in patches > 2 ha.
- Retain small buffers of dead lodgepole around inclusions of other tree species.

- Retain small groups (> 2 ha) of dead pine.
- Delay underplanting of beetle-killed stands where remaining canopy is dense; focus control of minor vegetation where competition expected to be intense.
- Leave any slash > 15 cm in diameter where it lies.
- Reserve upland and riparian hardwoods from harvest.
- Create tall stumps or stubs as cavity sites in stands where other tree species have not been reserved from harvest, the harvested area is extensive (> 100 ha), and the harvest method permits.
- Stubs should be restricted to trees > 23 cm DBH.
- Follow regulatory guidelines plus when harvesting near streams and rivers (plus refers to additional measures for small streams, see detail below).
- Retain unharvested riparian buffers around wetlands and small lakes.
- Avoid salvage in areas where pine represents < 40% of the species mix.
- Plan both areas to be reserved from harvest and areas to be harvested as large blocks.
- Plan harvest over larger areas (e.g., up to 1000 ha) quickly and deactivate roads when finished. Avoid small patch-wise approaches.
- Reserve half of each known lodgepole pine ungulate winter range from salvage (equivocal, see section 5.2).
- Leave areas should include areas with dense populations of fish species that are highly sensitive to salvage logging, and for which the province has high stewardship responsibility.
- Avoid storing logs in lakes.

Studies reviewed were used to evaluate whether the initial recommendations remain valid, whether they should be modified, and whether other approaches should be considered. The present recommendations are collected as either largely stand-level practices or primarily landscape-level planning, and challenged by findings to date in sections following.

5.1 Review of Stand-level Practices

Observations and recommendations offered by Bunnell et al. (2004) are summarized and evaluated in terms of recent studies within the Mountain Pine Beetle Initiative. Martin et al. (2006) made similar recommendations with two exceptions. Martin and colleagues make more specific recommendations about hardwoods, namely: retain all possible deciduous trees (preferably in patches with conifers); patches should be > 1 ha, larger (> 10 ha) to retain species dependent on old forest cover. They also recommend spreading salvage activities across the landscape, whereas Bunnell et al. (2004) recommended they be concentrated. Studies to date suggest the latter recommendation will do more to sustain biodiversity (e.g., McNay et al. 2008; Munro et al. 2008).

5.1.1 Upland

1) Retain tree species other than lodgepole pine, ideally in patches > 2 ha.

Bunnell et al. (2004) noted that leaving all non-pine tree species, rather than simply clearcutting all trees, would greatly help to sustain vertebrate species, because many vertebrate species can persist in salvage logged stands provided other tree species, plus those in riparian areas, are maintained. They estimated that for the three Defined Forest Areas they reviewed, retaining species other than lodgepole pine during logging would help retain about 60% of native vertebrate species as well as bryophytes, lichens, and non-pest invertebrates. Retaining non-pine species also helps timber flow, hydrology patterns, and riparian function.

Desirable outcomes attained include:

- Significant contributions of non-pine species to ECA and likely lessened peak flood (Alila 2008; Huggard 2008c).
- Among birds, foliage gleaners naturally decline under beetle attack when lodgepole is a major component of the stand (Stone 1995; Martin et al. 2006; Norris and Martin 2008). Maintaining non-pine species helps to maintain a sizeable component of the bird fauna (Martin et al. 2006).
- Maintaining non-pine conifers also would help maintain red squirrels and species foraging on them, such as northern goshawk (Stone 1995).
- The value of retaining non-pine species in riparian areas is affirmed (see Riparian below).
- Non-pine species in the understorey generally release better than pine and help provide merchantable timber in the mid-term and habitat structures sooner than if they were eliminated during salvage operations (e.g., FPB 2007a; Astrup et al. 2008; Coates 2008).

Patchwise retention is preferable to dispersed retention:

- Patches sustain lower rates of windthrow than does dispersed retention (Chan-McLeod 2007).
- Birds species generally associated with mature forests prefer blocks with retention, regardless of cutblock size (Chan-McLeod et al. 2008).
- Composition of the retention patch is important: live non-pine species and hardwoods are best (e.g., Martin et al. 2006). Plots reported by Martin et al. (2006) and Drever et al. (2008) were sometimes completely surrounded by salvage logging, yet species richness across the plots was retained.

Potential negative effects are that retained non-pine species will reduce light interception, thereby potentially affecting subsequent regeneration (Huggard 2008b), but amounts of non-pine species typically are small.

Current finding The recommendation is affirmed. The preferred patch size of > 2 ha is derived from references cited directly above plus a report being prepared by R. Botting and C. DeLong entitled "Will small forest patches maintain the species richness of macrolichens and bryophytes growing on decaying logs?".

2) Small buffers of dead lodgepole around retained inclusions of other tree species will help to sustain biodiversity.

Although retention is best anchored on live trees, buffering retention with dead pine can usefully increase patch size and add important habitat structures. Botting and Delong (2008) found that retention patches sometimes were too small to maintain the abundance of the non-vascular plant species they studied; buffers of dead pine may help expand areas of mostly live trees to increase patch size. They subsequently recommended 2 ha (R. Botting and C. Delong, "Will small forest patches maintain the species richness of macrolichens and bryophytes growing on decaying logs?", in preparation). Huggard (2008b) indicates that about 20% of trees in a dead lodgepole pine buffer would remain standing for 30 years, after which the rate of fall declines. Dead pine buffers will provide snags and down wood over time. Retaining dead pine reduces light interception, thus possible regeneration rates, but also reduces ablation rates, thus peak flows, at least through the grey stage (Boon 2008; Huggard 2008b; Cichowski 2009; Rex et al. 2009).

Current finding Small buffers of dead lodgepole retained around inclusions of other tree species help to sustain biodiversity.

3) Retaining small groups (> 2 ha) of dead pine will help to retain biodiversity.

Even where retention cannot be anchored on live trees, retaining dead pine will have ecological benefits. Although no studies specifically examined retention of small patches of dead pine, several studies examined uses of dead pine stands; still others provide insight into their value:

- Huggard (2008 a,b) indicate that about 50% of the trees will remain standing through 10 years or longer when retained patchwise (Chan-McLeod 2007).
- For at least 5 years post-beetle attack, many species remain relatively abundant in dead pine (Stone 1995; Chan-McLeod 2007).
- Dead pine is important to some species. Dead pines provided 76% of the nest trees for black-backed woodpecker (Bonnot 2006; Bonnot et al. 2008).
- Dead pine allows sufficient light into the forest floor that shrub responses will encourage early seral species (Huggard 2008a; Kremsater et al. 2009).
- Other vertebrates also may benefit from inclusions of dead pine, though effects have been evaluated over larger scales. Although the use of dead stands by caribou varied between herds (Cichowski 2009; Seip and Jones 2009), some herds used dead pine, possibly by exploiting small patches of living trees.
- The size of trees retained is important, even when they are dead. In burnt forests of Montana, all cavity users, except mountain chickadee, nested in trees larger and taller than what was available in salvaged stands (Hutto and Gallo 2006). Snags of larger diameter favour cavity nesters and generally remain standing longer (Huggard and Kremsater 2007).
- Retained dead trees will provide a range of decay stages required by cryptogams on down wood (e.g., Botting and Delong 2008, 2009).

Current finding Findings affirm the utility of retaining dead trees, but also indicate that retention should emphasize appropriate trees, including larger and non-pine trees. The preferred patch size of > 2 ha is derived primarily for considerations of windthrow and Botting and DeLong (2008).

4) Delay underplanting of beetle-killed stands where remaining canopy is dense; focus control of minor vegetation where competition expected to be intense.

Huggard (2008a) provides data suggesting that underplanting should be implemented quickly on more open sites, but delayed where remaining dead trees are relatively dense. Bunnell et al. (2004) noted that the percentage of vertebrates benefitting from shrub cover is uncommonly high in lodgepole-dominated forests and occurs primarily because lodgepole pine is a fire-adapted species, subject to frequent disturbance. From the perspective of shrub-using species, large areas can be harvested, provided non-pine species and small groups of dead pine are retained to support other wildlife species. To attain the full potential positive response of early seral species to salvage logging, control of minor vegetation should be used sparingly. Current work suggests that understorey vegetation response to increased light is more dramatic on moist sites than on drier ones (Coates and Budhwa 2007; Hawkins and Rakochy 2007; Delong 2008). Control of understorey should be limited to moist areas where pine grass, other grasses or shrubs are most likely to compete significantly with crop trees (e.g., alder reported as a problem near Prince George; G. Dow, BC MoFR, pers. comm., 2009).

Current finding The sparse new evidence suggests that minor vegetation can hinder regeneration in local situations. Current work indicates that vegetation management can be focused rather than widespread; the recommendation stands.

5) Leave any slash > 15 cm in butt end diameter where it lies.

No vertebrate species showing strong positive associations with downed wood also favours lodgepole pine. Numerous lichen and bryophyte species, however, require downed wood; affinities have been documented within the SBS (Botting and Delong 2008, 2009). Most species responsive to down wood do better when larger diameters are available. Botting and Delong (2009) noted that lodegpole pine decay classes 1 and 2 were little used by the species they studied; they highlighted the importance of well-decayed wood and of retaining a mix of species of down wood. Leaving dispersed CWD benefits small species that disperse poorly, such as some mosses and lichens (Bunnell et al. 2009a).

Current finding Botting and Delong (2008) found no trend of lichen and bryophyte diversity with CWD diameter in British Columbia; the much more broadly based synthesis of Bunnell et al. (2009a) reported relations in several studies. The review leading to the recommendation is not challenged; the recommendation remains.

6) Reserve upland and riparian hardwoods from harvest.

A total of 45 vertebrate species within the three TSAs treated by Bunnell et al. (2004) prefer hardwood trees or stands, including many cavity nesters and bats, as well as epiphytes. Reserving riparian areas (usually dominated by hardwoods) and upland hardwoods from harvest is critical. The value of retaining hardwoods in riparian (see below) and upland sites is affirmed. Martin et al. (2006) make a compelling case for aspen on upland sites.

Current finding The recommendation is affirmed.

7) Create tall stumps or stubs as cavity sites where other tree species have not been reserved from harvest, the harvested area is extensive (> 100 ha), and the harvest method permits.

A total of 47 terrestrial vertebrate species within the three TSAs reviewed use cavities for nesting or denning. Only three of the species commonly use lodgepole pine for their cavity sites (black-backed woodpecker, northern flying squirrel, and red squirrel). Dead lodgepole pines, however, also serve as foraging and perching sites for other species. Maintaining cavity users emphasizes the importance of non-pine species: hardwoods are often used preferentially as cavity sites, and non-pine conifers will provide nest cavities after the current cohort of dead pine has fallen. Plans to maintain the supply of cavities should consider stubbing, the character of the non-harvestable land base (is it mostly dead pine or are there live trees of other species?) and the character of retained patches (again, are they mostly dead pine or is there an abundance of other live trees?) and aim to provide snags beyond the 20 years or so that dead lodgepole will contribute.

Current finding There are no data in reports reviewed related to stubbing. Findings do not directly address the issue and neither rebut nor affirm the recommendation that was based on first principles. Assessing the extent of retained dead trees or unsalvaged areas is necessary to determine potential contributions of stubbing. The FPB (2009) suggested that recent stand-level retention was adequate in many blocks harvested since 2008 in beetle-attacked regions, but merged over larger areas than cutblocks to create very large openings with lower levels of retention than directed by the Chief Forester. Stubbing could be an important future practice to augment retention levels, and evaluation of its effectiveness is important.

8) Stubs should be restricted to > 23 cm DBH trees.

Current finding There are no data reported on nest sites in stubs. Recent review of the literature suggests that 23 cm DBH will accommodate many cavity-nesting species (Bunnell et al. 2009a). Note, the apparent necessity of stubs should be evaluated before starting stubbing (recommendation 7 above).

5.1.2 Riparian

Within the three TSAs treated by Bunnell et al. (2004)—the Lakes TSA, Prince George TSA, and Quesnel TSA—about 50% of terrestrial vertebrates are more abundant or productive within riparian areas. There are somewhat more late-seral associates (22) than early seral associates (20) among species that prefer riparian areas. Aquatic organisms also benefit from adjacent riparian vegetation. Leaving riparian areas intact is critical to mitigating negative impacts on a wide range of species. When Bunnell et al. (2004) wrote, the *Forest and Range Practices Act* had yet to be adapted, but was imminent. They recommended:

9) Follow regulatory guidelines plus when harvesting near streams and rivers.

These were not followed and current findings reveal that they should have been. "Plus" refers to additional measures around small streams. Few streams flow primarily through lodgepole pine (Hassan et al. 2008; Hinch and Mellina 2008; Rex et al. 2009), which both mutes potential effects and emphasizes the importance of the recommendation by Bunnell et al. (2004) that species other than pine be retained in riparian areas. Consequences of harvesting pine in riparian areas are long lasting (Nordin et al. 2008), while consequences of leaving it have had no negative effects in the first years post-attack.

- CWD input: Hassan et al. (2008) suggest no major effects of large-scale, unsalvaged bark beetle mortality, but their budgeting approach appears to have underestimated how debris input is concentrated in time following large-scale attack. Nordin et al. (2008) and Wei (2007b, 2009) provided direct measures of large, long-lasting effects of harvesting riparian areas; 20 to 30 years was insufficient for recovery. Wei (2009) reported little difference in coarse woody debris input between unharvested beetle-killed stands and comparable unattacked reference sites.
- Temperature: Evaluation of potential effects on organisms was limited to fish. Although salvage logging clearly reduced stream shading (Nordin et al. 2008), effects on rainbow trout appear minimal under current climate with up to about 50% reduction in canopy cover (Maloney 2004; Mellina 2006; Hinch 2008). Bull trout, however, require cooler waters and their absence from sites where they were expected may be due to stream warming resulting from riparian removal (Hinch and Mellina 2008). Again, effects can be long lasting (Nordin et al. 2008). Unharvested sites continue to provide shade through the grey attack phase (Rex et al. 2009).
- Attempts to investigate effects on bull trout were foiled because few candidate streams were found (Hinch and Mellina 2008). The study surveyed 56 streams and found that fish species richness was highest in streams flowing through forested or older logged areas; bull trout were found only in forested streams. Bull trout are fall spawners that prefer cooler water. Both these features make them susceptible to climate trends, thus more dependent on shade, because effects of summer drought and warming are higher in the fall than earlier in the year.

There appears to be little reason to salvage riparian areas, but several reasons not to. Usually there is very little pine within 10 m of riparian areas, so removing it achieves little economic benefit. Leaving it has no negative impacts over the term of studies reported here. Salvage logging it has long-term negative consequences particularly on coarse woody debris input and channel morphology, but also on broader riparian function as assessed by RREE. Rex et al. (2009) found that riparian zones of grey attack stands were properly functioning according to the RREE, whereas harvested areas were properly functioning, but with some risk (impairment). Harvested sites that were properly functioning with a low level of risk generally had buffer widths > 10 m. Findings are consistent across three major studies (Maloney 2004; Nordin et al. 2008; Rex et al. 2009). The minimum prescription for salvage (no buffer on small streams) did not maintain all management objectives; key failings include long-term decrease in large woody debris, decreased litterfall, and decreased shade.

Current finding Do not salvage within 10 m of even small streams (e.g., S4). A distinction may be possible between lake-headed and headwater streams, when fish requiring cooler water (e.g., bull trout) are not present. Hinch (2008) deduced that lake-headed streams with rainbow trout may be able to support more aggressive streamside harvesting, which would remove most commercial timber within the riparian zone while retaining deciduous vegetation and non-commercial as well as some commercial trees. That relaxation is not universal and is potentially contrary to findings of Maloney (2004), Nordin et al. (2008), and Rex et al. (2009).

10) Retain unharvested riparian buffers around wetlands and small lakes.

Current finding There are no findings in reports reviewed relevant to the recommendation. It is based on the fact that hundreds

of species depend on wetlands and small lakes, and other research suggests that drying effects of climate change are buffered by surrounding forest. The review leading to the recommendation is not challenged; the recommendation remains.

5.2 Review of Landscape-level Planning

Observations and recommendations offered by Bunnell et al. (2004) are summarized and evaluated in terms of recent studies within the Mountain Pine Beetle Program.

11) Avoid salvage in areas where pine represents < 40% of the species mix.

- Bunnell et al. (2004) offered this recommendation to help sustain future economic opportunities and biodiversity. There are two issues: losses and gains.
- Obviously, future economic opportunities are lost as non-pine trees are salvaged. The likelihood of loss through ecological degradation of areas with up to 40% dead trees appears small (recommendation 3 above). The economic value of retention of future opportunities is significant. Likewise gains of avoiding salvage in areas with < 40% pine are considerable (see Hawkins 2006a).
- Bunnell et al. (2004) noted that few vertebrate species show a preference for lodgepole pine. Some do seek lodgepole, particularly during insect outbreaks. Black-backed woodpecker benefits from beetle epidemics (Bunnell et al. 2002; Bonnot 2006) as they provide both more food and nesting sites. Bonnot (2006) found that 76% of the nest trees were ponderosa pine snags and salvage logging had little effect on nest survival. Bunnell et al. (2004) also observed that 56 of the species present within the three TSAs favoured late-seral stages (39 birds and 17 mammals). Many of these (29) require late seral stages largely because they require cavity sites in trees large enough to provide habitable cavities. Lodgepole pine rarely attains that size. Moreover, lodgepole pine simply does not live long enough to produce the attributes normally considered to characterize old growth. In short, biodiversity largely depends on non-pine trees. Ecological values gained by retaining non-pine species extend beyond contributions to biodiversity; some are listed under recommendation 1 above.

Current finding The recommendation is affirmed. As well, where site conditions suggest longer recovery times (for example, due to lower productivity), avoid salvage harvesting or use a lighter touch than in more productive or resilient stands. Similar care should be taken in rarer ecosystems.

12) Plan both areas to be reserved from harvest and areas to be harvested as large blocks.

Clearcutting large areas has negative effects on hydrology and, likely also, on biodiversity.

- In terms of proportion of area logged, the threshold value for responses in peak flow and flooding appears to be between 30 and 50% (Alila 2008; Kuraś et al. 2008). Roads may actually mitigate peak flow (by redistributing flow) up to about 30% of area harvested (Kuraś et al. 2008). By 50%, removal effects appear substantial. Data of Bethlahmy (1975) suggest it is closer to 30%. Weiler et al. (2009) suggest scale effects, making a simple threshold unlikely.
- Results suggest that logging dead pine stands increases the total amount and rate of spring snowmelt over what would have otherwise occurred; the effect lasts about 15 years (Teti 2008).
- Removing trees and bryophyte layers increased the volume of water entering the soil, thus slowing runoff (Carlyle-Moses and Burles 2009).
- Standing dead pine contribute to lowering the ECA (Huggard 2008c).
- Peak flow regime is much more sensitive to logging in higher elevations (Alila 2008), suggesting that these areas should be left unharvested.
- Recovery times predicted under current approaches are likely to be wrong and peak floods may be underestimated (Alila et al. 2009).
- The FPB (2009) noted that lack of landscape-level planning led to adjoining areas often being harvested, collectively creating large areas with little overall retention (even though recently harvested stands had reasonable retention levels). This finding emphasizes the importance of tracking retention and planning over large areas.

In deciding where to concentrate harvest, also consider where to leave large areas unharvested and how to distribute within-stand retention. Distributing within-stand retention was addressed in recommendations 1 through 3. At the landscape level, consider where to leave large areas unharvested. Although later stages of beetle kill have not been documented, results to date indicate that retaining dead trees is either beneficial or has no reported negative effects other than on light interception. Lodgepole pine regeneration under most dead canopies will be delayed until light levels increase, but more shade-tolerant species will grow well under dead canopies (e.g., Coates and Hall 2006; Coates et al. 2006; Astrup et al. 2008).

- Standing dead trees continue to intercept some snow and do not affect ablation significantly (Boon 2008; Teti 2008).
- Wei (2009) reported CWD inputs could lead to changes in channel morphology, but it is too early to assess consequences.
- Seip and Jones (2009) reported no difference in terrestrial lichens (caribou forage) below dead stands and stands that were salvage logged, but Cichowski (2007) and Williston and Cichowski (2006) reported declines in lichens that sometimes rebound in a few years and sometimes remain reduced. They are still assessing reasons for responses.
- Caribou winter use in salvaged blocks was < 25% of that in clearcuts and much lower than in stands not salvaged (Seip and Jones 2009). Reponses of herds, however, appears variable (e.g., Cichowski 2009).

Current finding The utility of this recommendation is affirmed. However, we are not far enough post-attack to know whether subsequent accumulations of dead wood will prove detrimental to stream hydrology or to caribou.

13) Plan harvest over larger areas (e.g., up to 1000 ha) quickly and deactivate roads when finished. Avoid small patchwise approaches.

- Roads are detrimental to many wildlife species; effects on hydrology are not well addressed, remain unclear, but are potentially unwelcome. Only one study addressed wildlife and roads explicitly. Munro et al. (2008) noted that grizzly bears were significantly more likely to die from human intervention in landscapes with high road density and access. Data on impacts of roads on hydrology remain ambiguous, likely a product of scale with effects being localized.
- Dykstra and Braumandl (2006) noted that to preserve beta vegetation diversity (landscape-level diversity rather than site-level diversity) and the successional potential of vegetation communities, a range of intact ecosystem types (i.e., site series) within stands and across landscapes in salvage areas should be left unsalvaged.

Current finding Although data are sparse, the recommendation is affirmed. Large salvage blocks should not come at the expense of keeping examples of distinct ecosystems unmanaged, nor be large enough to affect hydrology concerns noted under recommendation 12.

14) Reserve half of each known lodgepole pine ungulate winter range from salvage.

The primary impacts of not salvaging half the winter range were surmised to be through snag fall and accumulated debris impeding access to and growth of terrestrial lichens. The primary advantage to caribou would be the provision of substrate for arboreal lichens. Net impacts would thus differ between caribou herds. The utility of this recommendation remains equivocal. Huggard (2008a) collated existing data on the rate of snag fall. Seip and Jones (2009) found no difference in terrestrial lichen between salvaged stands and unlogged, dead stands. Cichowski (2007) and Williston and Cichowski (2006), however, report declines in lichens in unlogged stands after beetle attack that sometimes rebound in a few years and sometimes remain low. They are still teasing out reasons for responses. More time is required before relations between ease of movement or terrestrial lichen abundance and debris accumulation can be developed.

Current finding The recommendation is neither affirmed nor discredited. It is expected to have different consequences for different caribou herds. It is retained as a working hypothesis for guidance to salvage in ungulate winter ranges.

15) Leave areas should include areas with dense populations of fish species that are highly sensitive to salvage logging, and for which the province has high stewardship responsibility.

Bunnell et al. (2004) noted that these species included the pygmy whitefish, mountain whitefish, rainbow trout, cutthroat trout, coho salmon, bull trout, and Dolly Varden, and provided distribution maps. Recommendation 9 addressed streamside retention; embedding candidate streams in basins with additional retention may be possible during landscape planning. That is particularly true, given that there is little evidence of negative effects of leaving dead pine and far more of negative effects of harvesting it in terms of stream features (see recommendation 9). Currently, bull trout appears more vulnerable than rainbow trout (Hinch 2008; Hinch and Mellina 2008).

Current finding The recommendation is affirmed by current data (recommendation 9) and freshwater species should be considered when evaluating where to leave larger areas unsalvaged.

16) Avoid storing logs in lakes.

This recommendation was initially derived by Bunnell et al. (2004) from first principles. There is no evidence that it occurs, and no studies directed to the question.

Current finding There are no findings in reports reviewed relevant to the recommendation. The review leading to the recommendation is not challenged; the recommendation remains.

6. Knowledge Gaps: Summary Statement

This section summarizes major knowledge gaps remaining across elements of the three broad topics: habitat attributes, attendant processes, such as light and snow interception, and direct effects on wildlife. It includes questions raised by review and attempts to assign a broad priority. It is structured to reflect the questions raised by early reviews.

6.1 Habitat Attributes and Elements

Bunnell et al. (2004) posed five questions that would inform forest practices and likely responses of biodiversity:

1. What is the most effective way of using fire to encourage regeneration in harvested stands?
2. Does prescribed fire have a role in abatement of hazard in unsalvaged stands?
3. Can sites requiring vegetation management be clearly defined?
4. What are the fall rates of dead trees (discussed under 6.2, processes)?
5. What are the consequences of debris levels in unharvested areas?

Reviewed papers documenting stand structures after beetle attack address Question 4 directly and 5 incompletely. We found no papers examining the role of fire in regeneration and hazard abatement, although one examined the effects of fire on beetle spread at a landscape scale (Barclay et al. 2006). No papers looked directly at where vegetation management is best practiced, although a few document where understorey response is likely high (e.g., Coates and Budhwa 2007; Hawkins and Rakochy 2007; Delong 2008). Some papers document downed wood levels after the beetle (Hawkes et al. 2003, 2005; Dykstra and Braumandl 2006; FPB 2007a) and one relates these to organisms (Botting and Delong 2008). Rates of snag fall have been adequately addressed (more details are found in sections 2, 3, and 6.2 for snag fall).

Several authors in Safranyik and Wilson's review (2006) also identified issues regarding stand structure to be addressed in CFS's subsequent research:

- How does advanced regeneration release and how much new regeneration exists in stands of different successional stages?
- How does stand structure respond to harvest and salvage? What tree species are left?
- What is the nature of retained patches within salvage cutblocks?
- What is the state of retention of major habitat elements?
- What are the temporal trajectories of major habitat elements in unsalvaged stands?
- What stand features confer resilience to attack?

The stand structure papers we reviewed focus on the first question of regeneration and release, and this question seems well answered, especially in the SBS zone (many references, see sections 2.1 and 8.1.1). Presence of existing understorey regeneration is difficult to predict and varies with location more than with site conditions.

- Non-pine understorey tree species release well after mountain pine beetle.
- Overstorey species, including lodgepole pine, also release.
- The live overstorey and existing understorey sometimes result in stocked stands 25 years after beetle attack, but often stands are not fully stocked.
- The remaining live trees and existing regeneration provide important habitat structures as well as mid-term timber opportunities.

Light interception is key to regeneration and has been well documented for only a few sites (see section 6.2, processes). Hawkins and Balliet (2009) promise a review of studies of secondary structure (tree regeneration) after the beetle.

Question 2 of Safranyik and Wilson (2006) is documented to the extent that it is known that overstorey species, including lodgepole pine, release after harvest. There is no overview of the extent to which opportunities for retaining non-pine species are enacted. Questions 3 and 4 have been partially addressed for limited areas (e.g., Chan-McLeod 2007; Chan-McLeod et al. 2008; FPB 2009); detail is sparse. Trajectories of stand elements in unsalvaged stands (Question 5) have been addressed to different degrees for different elements: well addressed for snags (e.g., Huggard 2008a), less completely for downed wood (Hawkes et al. 2003; Dykstra and Braumandl 2006; Waterhouse et al. 2008), and in scattered detail in several reports for understorey (some caribou studies).

Question 6 has also been partly addressed. Stand features conferring resilience to attack have been documented (low density, non-stressed trees, e.g., Brockley et al. 2008a), but also acknowledged as not being effective when beetle populations are high.

Attack rates in young stands have been documented (e.g., Hawkins 2008; McLaughlan and Brooks 2008; McLaughlan and Hodge 2008). Several other projects have attempted to predict where beetles will attack and which stands are most susceptible, but those topics were not included in the scope of this review.

Knowledge gaps relative to these questions are presented in approximate order of decreasing certainty. The reverse order broadly reflects research need, as assessed primarily by potential impact on biodiversity (i.e., the most important points for research are listed last).

- Most questions relevant to advanced regeneration appear well addressed, especially in the SBS.
- Trajectories of key stand elements have been variably addressed—sufficiently for snags, sufficiently for down wood (there could be problems 5–10 years from now), and incompletely for shrubs, but shrub trajectories are less likely to have negative effects.
- Stand resilience has been addressed and current knowledge appears sufficient to guide management decisions.
- Downed wood levels are known only for some areas and are highly variable. Currently, it does not appear to warrant study but could eventually become a problem in terms of hazard abatement and barriers to grazing or browsing animals.
- The potential role of vegetation management has not been documented; generally, the responses of shrubs are not well quantified in beetle-killed areas. However, there is evidence that shrubs respond well; impacts of vegetation management are typically short and responses will be highly variable locally and likely well anticipated by practitioners. Despite the lack of study, it is likely adequate to rely on local judgement.
- The role of fire in hazard abatement or encouraging regeneration in beetle-killed stands does not appear to have been addressed. Currently there appears to be little reason for concern about regeneration, but hazard abatement could become a problem.
- The nature of stands after salvage is inadequately described, but is critical in assessing contributions to sustaining biodiversity as well as forecasting mid-term timber supply.
- The nature of retention patches and levels of retention of major habitat elements are inadequately documented (see section 2.2). Although temporal trajectories are reasonably well documented for release of live trees, rates of snag creation, snag fall, and accumulation of down wood, the amounts actually retained are poorly documented.

6.2 Processes

Three broad questions relating to processes were posed by Bunnell et al. (2004):

1. Does the increased cut rate produce undesirable effects on hydrology, water temperature, and turbidity or sedimentation?
2. Do streams flowing through lodgepole pine stands acquire undesirable characteristics once the pines die?
3. What are the fall rates of dead trees?

Other uncertainties were addressed during review. Question 3 has been well addressed. Questions 1 and 2 have been partly addressed. The questions explicitly or implicitly acknowledge the influence of a wide range of processes. Findings and knowledge gaps about these processes are presented in approximate order of decreasing certainty. The reverse order broadly reflects research need.

- We consider current data on snag fall rates and canopy loss in pine snags adequate to guide management.
- Negative effects of salvage logging on stream characteristics (e.g., lack of shading, too much large woody debris) are sufficiently well documented that current practices in riparian areas should be changed.
- Windthrow, including the potential effects of patch size, is sparsely documented. Available data (Chan-McLeod 2007; Waterhouse et al. 2008), however, yield the same rank order as found in stands of other conifer species without beetle kill. Although uncertainty remains high, given the high local variability, it is unclear how further local study would provide general guidance.
- Rates of snow interception and ablation in areas of salvaged and unsalvaged beetle kill appear quantified well enough to document direction of response and approximate rate of change in stream hydrography (more so for refinement of ECA estimates than for numerical modelling).
- Current models of climate variables accurately predicted spread and extent of beetle attack. Utility of these models might be refined to accommodate jack pine and applied nationally. Provincially, when coupled with projected climate change effects on lodgepole distribution, the models may reveal refugia for lodgepole pine, where natural genetic variation could be sustained.
- We found two studies directly addressing water chemistry, turbidity, and sedimentation (Hinch 2008; Brown et al. 2009). Brown et al. (2009) found no strong effects of mountain pine beetle; underlying geology had the most pronounced effect.

They also reported that turbidity was a function of water crossings. Hinch (2008) reported that suspended summer sediments remained low 6 to 10 years after logging. We encountered no other "red flags" suggesting this was a high research priority. Brown et al. (2009) observed that Routine Riparian Effectiveness Evaluation (RREE) was a useful assessment tool.

- Responses of stream temperature appear reasonably well predicted by the model of Mellina et al. (2002). Natural variability of fluctuations makes the consequences to fish more equivocal, particularly for species requiring cooler water (e.g., bull trout). Effects on cool-water species remains a research gap. Hinch and Mellina (2008)'s efforts to close that gap suggest considerable map and ground work would have to precede study.
- Long-term effects of the consequences of large woody debris resulting from salvage logging remain equivocal, but appear more likely to be negative than positive. Hassan et al. (2008) suggest little effect based on budgets; retrospective studies of Nordin et al. (2008) reported long-lasting effects. The review by Huggard (2008a) suggests that evaluating effects of woody debris budgets would have to extend at least 10 years to incorporate 50% of the natural fall down of beetle-killed snags. Hassan et al. (2008), Nordin et al. (2008), and Wei (2009) all report high inter-basin variability. There may now be sufficient data that a small synthesis could be undertaken from the raw data, but success appears unlikely because methods differ markedly between studies.
- Streams flowing through beetle-killed, pine-dominated vegetation resources inventory (VRI) cover types acquire potentially undesirable characteristics (Wei 2009), but these effects are not as large or possibly as long-lasting as those reported for streams that were salvage logged (Nordin et al. 2008; Rex et al. 2009). Effects are highly variable (Wei 2007b, 2009). Given the documented rates at which beetle-killed stands break up, it is unclear that immediate research would be insightful, but some long-term studies have been initiated (e.g., Wei 2009) that merit continuing.
- Decisions of where and when to plant are affected by light interception by remaining foliage and branches on unsalvaged trees. Although some studies have looked at light transmission in depth, those studies do not encompass many BEC zones. Light interception has significant management consequences; any study should include variability in transmission by non-pine species, snag age classes, and seedling response.
- The ability to obtain more data-based and credible forecasts of effects on forest harvesting on stream hydrographs appears promising. There are, however, pros and cons to continued immediate investment. Developing numerical models like DHSVM requires instrumented sites and, in terms of the synthetic data used to drive them, longer time frames of actual data are more informative, requiring investment in continued data acquisition. Conversely, Hélie et al. (2005) suggest that peak effects from beetle attack may not occur for 15 years, suggesting uncommonly long-term study. Useful retrospective opportunities appear exhausted, and the documented lack of generality of individual stream response further hinders investment. It would be useful to re-visit attempts at scaling up in 5 years' time. Currently, numerical modelling is primarily useful for effects immediately following forest removal. It does not function well without employing ECA. A consistent problem is that results are not readily generalizable (Wei 2007a; Alila 2008; Nordin et al. 2008).
- Negative consequences of large-scale salvage logging on stream hydrographs appear reasonably documented (larger peak flows, greater flood frequency). Thresholds are not clear, but appear to be between 30 and 50% of the area. Alila et al. (2009) make a compelling case that much of current findings derive from misleading analyses. Given the uncertainty and the potential impacts, investment in re-analysis appears worthwhile.

6.3 Direct Effects on Wildlife

Four broad questions relating directly to wildlife were posed by Bunnell et al. (2004):

1. Which species are retained in large unharvested areas of beetle-killed lodgepole pine?
2. Which species continue to use retained patches (live and dead) in harvested areas?
3. Which species use lodgepole pine stubs created during salvage, and which characteristics of stubs are sought?
4. Are cavity users being lost from the study or management area?

Question 1 was partly addressed for caribou and birds; in the latter instance, "large" areas were about 200 ha. Through the grey phase of attack, responses differed between caribou herds: in one instance caribou avoided salvage-logged stands during winter; in the second, they persisted in foraging in beetle-killed stands. The data of Martin et al. (2006) suggest that retention of small amounts of aspen over large areas sustains bird species richness up to pine mortality rates of about 60%. The data of Chan-McLeod (2007) and Chan-McLeod et al. (2008) document bird species in unharvested beetle-killed areas; like Martin et al., they found retention benefitting those species typically associated with mature forest. Given the variety of forest conditions and structural composition extant, the question is incompletely addressed.

Question 2 was addressed by Martin et al. (2006) for birds in leave patches in which aspen was present. No species were lost from the larger area up to about 60% mortality of pine. Chan-McLeod (2007) and Chan-McLeod et al. (2008) also note that retention patches benefit many bird guilds. Martin et al.'s data also provide a partial answer to Question 4; under the constraints of 60% pine mortality and many leave patches containing aspen and other non-pine conifers, species of cavity nesters were not lost. Question 4 is difficult to address due to lack of pre-beetle data in potential study areas. Question 3 was not addressed.

Although the current beetle outbreak is likely near the end of its course in British Columbia, Carroll et al. (2004) suggest that beetle populations will remain higher than normal for decades, which we acknowledge in assessing research priorities below. We also consider that at the broad level of forest structure, wildlife findings could apply to other forms of beetle mortality as well, such as spruce bark beetle, and that the documented rates of stand breakup indicate that the peak transition from dead tree to coarse woody debris has not yet occurred in many beetle-killed stands. All topics have high levels of uncertainty, so they are arranged in decreasing order of priority, acknowledging the conditions noted.

- Studies reviewed for this report suggest there is opportunity for synthesis of data, from existing reports and the larger literature, to document forest structures resulting from practices in the face of beetle attack and impacts of these structures on vertebrates. We rank it highly because it could guide subsequent, more focused studies effectively.
- Does stubbing during salvage operations help to sustain cavity nesters? Data from other forest types suggest it should, but the process bears additional costs and should be evaluated before being adopted in more areas or rejected.
- Reponses of downed wood associates are incompletely documented. The single study suggests that retention patches are too small.
- Response of two caribou herds to initial phases of beetle attack differed. The possibility of continued study presents a dilemma: although it would most clearly document the probable causes of response, most beetle-killed trees will still take years to become coarse woody debris. Responses of caribou to beetles very likely will depend on whether dead pine is standing (with sufficient limbs remaining to intercept some snow or provide substrate for lichens) or fallen.
- Leaving large areas of beetle-kill may remain an option. Despite the lack of pre-treatment data for comparison, it could guide future planning to know just which species are sustained and which become uncommonly rare in unsalvaged beetle-attacked forests.
- Some vertebrates detrimental to crop trees, particularly lodgepole pine, are encouraged by downed wood. Given that CWD input has not peaked and T. Sullivan is still evaluating influences of piling debris, the priority for examining the role of alternative treatments of debris is currently low.

7. Monitoring: Summary Statement

To evaluate the potential impacts of beetle attack and subsequent salvage operations on biodiversity, Bunnell et al. (2004) suggested a framework of three broad indicators and associated key questions. Because there was no experience of a beetle attack of this magnitude, the framework was based on first principles. An updated summary is as follows:

Indicator 1

During large-scale salvage operations, amounts and area of tree species other than lodgepole pine do not decline below those expected during normal operations.

- Are tree species other than lodgepole pine being removed at rates higher than planned or anticipated prior to salvage logging?
- Are riparian areas maintained during salvage logging?
- Where can the greatest gains be accrued by leaving extensive tracts of beetle-killed pine?

Indicator 2

The amount, distribution, and heterogeneity of stand and forest structures important to sustain native species richness are maintained over time.

- Are unharvested areas of lodgepole pine regenerating?
- What is the nature of retained patches within salvage cutblocks?
- Are major habitat elements retained?

Indicator 3

The abundance, distribution, and reproductive success of native species are not substantially reduced by salvage operations.

- Does evidence indicate species will be lost from large areas after beetle attack (unsalvaged) and/or after salvage logging?
- Do caribou continue to use lodgepole pine winter ranges after the pines die?
- Which species are still living in retention patches?

These questions all relate to monitoring, which was not the purpose of the Mountain Pine Beetle Initiative. Few reports reviewed address the questions directly; nevertheless a framework for effectiveness monitoring remains important. Using reports reviewed, we evaluate each question based on the following criteria: Was the question addressed? Is the question still important? Do other large questions appear important?

1) Are tree species other than lodgepole pine being removed at rates higher than had been planned or anticipated prior to salvage logging?

The consequences of removing non-pine species were addressed. Retaining it in salvaged stands:

- reduces resultant ECA, thus potential unwanted effects on stream characteristics (Alila 2008; Huggard 2008c);
- keeps more bird species (Stone 1995; Martin et al. 2006; Chan-McLeod 2007; Chan-McLeod et al. 2008);
- encourages red squirrels and species foraging on them, such as northern goshawk (Stone 1995);
- reduces negative impacts in riparian areas (section 5.1; Nordin et al. 2008; Rex et al. 2009); and
- provides merchantable timber in the mid-term and habitat structures sooner than if existing regeneration were eliminated during salvage logging operations (e.g., FPB 2007a; Astrup et al. 2008; Coates 2008).

The degree to which non-pine species was removed is poorly documented. Removing it has major consequences, which affirms the question's importance. Current forest inventories show stands with non-pine species in the overstorey, but do not identify amount or composition of understorey species, which makes planning harvest approaches difficult except on a site-by-site basis.

Findings to date confirm the value of the question. It is critical in assessing outcomes, even when the effects of mid-term economic contributions are ignored. It stands as proposed.

2) Are riparian areas maintained during salvage?

Riparian areas and their values were not maintained during harvest. Negative impacts include:

- failure to meet the Forest and Range Evaluation Program (FREP)'s Routine Riparian Effectiveness Evaluation standards (Rex et al. 2009);
- excessive woody debris (Nordin et al. 2008);
- potentially long-lasting negative effects on channel morphology (Nordin et al. 2008; Wei 2009);
- reduced shading, warmer stream temperatures (Mellina 2006; Hinch 2008; Rex et al. 2009); and
- potential negative effects on fish species requiring cooler water (Hinch and Mellina 2008).

Findings confirm the value of the question and reveal the value of a 10-m buffer (Riparian Reserve Zone) around S4 streams (Rex et al. 2009).

3) Where can the greatest gains be accrued by leaving extensive tracts of beetle-killed pine?

The question addresses potential gains in maintaining biodiversity and in reducing negative consequences of widespread, scattered harvest and road construction. Negative consequences of roads are documented for wildlife (McNay et al. 2008; Munro et al. 2008), but remain equivocal for hydrology (Alila 2008; Kuraś et al. 2008). The value of extensive dead lodgepole pine to caribou appears to vary among herds (McNay et al. 2008; Cichowski 2009; Seip and Jones 2009) and studies to date may be too early to assess the impact. Alila (2008) found value in avoiding logging snowmelt-dominated basins in higher elevations. Models of Schnorbus et al. (2010) and Weiler et al. (2009) can inform which leave areas would have the greatest influence on mitigating peak flow when planning over large areas.

The question has value, but will likely remain difficult to address for consequences other than hydrology. Nevertheless, it holds considerable consequence to planning and holds heuristic value in guiding research.

4) Are unharvested areas of lodgepole pine regenerating?

Typically, yes. Many stands, even those labelled "pure pine," have secondary species in the overstorey (Burton and Brooks 2007), and many have abundant and variously developed understorey regeneration (Brockley et al. 2008a). New growth is often

delayed 4 to 5 years, with shade-tolerant species establishing before the less shade-tolerant lodgepole pine (Huggard 2008a). Regeneration's initial survival following salvage logging in pine stands is less well known than are growth rates under different light regimes (Huggard 2008a). Several studies have looked at light levels under pine (mostly in the SBS) and some project growth rates of regeneration (e.g., Astrup et al. 2008). Both low light levels and competition among understorey species can inhibit regeneration and growth of understorey trees. Herb and brush competition seem to be locally important, especially on moist, rich sites (Coates and Budhwa 2007; Hawkins and Rakochy 2007).

The question has value. Knowledge of regeneration is greater in the SBS than in other BEC zones.

5) What is the nature of retained patches within salvage cut blocks?

The question was partly addressed. Most studies incompletely documented sizes, configurations, tree species composition, and live versus dead components of retained patches. Studies usually focused on the nature of retained patches relative to responses of a single species or broader group with emphasis on the organism(s). Martin et al. (2006) noted that where aspen was abundant and retained in patches, nesting opportunities for birds were provided such that no species were lost from the study area (up to about 60% mortality of pine). Chan-McLeod (2007) and Chan-McLeod et al. (2008) recorded structural plots in retention patches and reported relative abundance of birds in unharvested areas and areas with different degrees of retention. Birds typically more abundant in mature forest benefitted from retention. Botting and Delong (2008) noted that liverworts, lichens, and mosses declined in abundance in the patch sizes they studied (generally < 2 ha).

The question remains critical to guiding practice that maintains biodiversity. Findings suggest a need to better document the types of retention patches left after salvage logging and how organisms relate to those patches.

6) Are major habitat elements being retained?

The question was partly addressed. For local areas, we know levels of trees surviving attack, rates of snag creation and fall, levels of downed wood, shrub and herb response, and growth of existing regeneration. We have limited ability to predict presence of non-pine species or levels of understorey stocking (e.g., Burton and Brooks 2007). Amount of downed wood varies greatly between sites (Dykstra and Braumandl 2006). Shrub and herb responses post-beetle seem to be regulated by moisture and nutrient levels (Hawkes and Rakochy 2007; Brockley et al. 2008a). We do not know how well habitat elements are retained after salvage logging (FPB 2009).

Findings to date reaffirm the importance of the question. Habitat elements are critical to biodiversity and although we know something of their abundance and trajectories post-beetle, their abundance and trajectories post-salvage logging are incompletely known. Focused synthesis might be able to extract trajectories from data of reports, but raw data is likely needed.

7) Does evidence indicate species will be lost from large areas after beetle attack (unsalvaged) and/or after salvage logging?

This question was posed because forest interior songbirds (e.g., golden-crowned kinglet) are among the species most likely to be heavily affected. Patches studied by Martin et al. (2006) generally were too small to address the question, and uncommon in their relatively high proportion of aspen. Paradoxically, the golden-crowned kinglet increased with increased levels of beetle infestation in the single study addressing the question (Chan-McLeod 2007). The kinglet is normally a foliage gleaner but also feeds on insects trapped in sap, which likely increased during the beetle attack. Birds associated with mature forests were found in harvesting treatments with retention sections, but in far lower numbers than in unharvested, beetle-killed controls (Chan-McLeod 2007).

The question is incompletely addressed. Attempts at answering this question should employ coarse-filter approaches prior to any detailed work (see Bunnell et al.'s 2009b summary assessment for a cost-effective and credible approach). That would include assessing the abundance of forest interior in the area of interest and identifying potentially sensitive species before embarking on field work.

8) Do caribou continue to use lodgepole pine winter ranges after the pine die?

The question was addressed. Caribou herds vary in their use of dead lodgepole (Cichowski 2009; Seip and Jones 2009) and studies to date may be too early to assess the impact. McNay et al. (2008) suggest the question is answered, but that may be premature given that the largest consequences on stand structure have yet to occur. Studies examining impacts of beetles and salvage logging on lichen abundance show some short-term declines in lichens in some areas (Cichowski 2007) and longer-term declines in others (Seip and Jones 2009). Williston and Cichowski (2006) explored mechanisms, such as increased competition between terrestrial lichens and kinnickinick and changes in light availability.

The question has value to the extent that caribou herds have value. There are benefits to continuing existing studies, but the major impacts of beetle kill on stand structure are likely at least 5 years away.

9) Which species are still living in retention patches?

This question represents the organism portion of Question 5, and was intended to document biodiversity values sustained by all forms of retention. Sensitive lichen and bryophyte species were not retained (Botting and Delong 2008). Contributions of aspen are well documented in a study by Martin et al. (2006) where aspen are common. Chan-Mcleod (2007) provides the single study evaluating the role of non-pine conifers and dead pine in more representative forest types, but it was of short duration.

The question is incompletely addressed, yet is key to sustaining biodiversity within salvage-logged areas. Both species response (presence/absence) and the character of the retention patch should be documented.

8. Annotated List of Studies to Date

This list is incomplete: we found references to studies that we could not retrieve; reports are available for only the initial portion of some studies. Some reports include only project descriptions of work that is just beginning or executive summaries of projects that have not yet submitted final reports. FSP reports with ambiguous publication dates are followed by an estimated date; FSP reports without attributed authors are attributed to "FSP."

Studies are annotated under a single topic, but are cross-referenced. Studies addressing more than one topic have their results specific to different topics summarized under more than one topic group.

8.1 Habitat Structure

8.1.1 Regeneration and Tree Responses

Alfaro, R.; Axelson, J.; Hawkes, B.; Copeland, A. 2008. Stand dynamics following mountain pine beetle outbreaks in central British Columbia: A synthesis for decision-support. FIA–FSP Project M07-5044, Executive Summary.

Purpose/Study Area General objectives implemented in Interior Douglas-fir (IDF) near Logan Lake are to determine:

- the composition of residual forests left after beetle epidemics;
- the future composition and growth of the residual forests; and
- how management interventions will alter affected stands, leading to long-term compensation for beetle-related losses.

Methods April 2006–March 2008: Three even-aged and three uneven-aged stands were sampled to reconstruct their dynamics. Where possible, stands were chosen that had previously been sampled by Hawkes et al. (2004) and Alfaro et al. (2004). Stand mensuration data included height, diameter at breast height (DBH), beetle status (healthy, green attack, red, or grey), crown class, and wildlife tree condition.

One regeneration recruitment subplot was established in each of the stand's four plots. Species, height, and density were recorded. A sub-sample of the regeneration tree species was aged to establish recruitment episodes. Increment cores were collected for dendroecological analysis to establish the beetle disturbance and stand development history for temporal reconstruction. In collaboration with the BC Ministry of Forests, these data were incorporated into model simulations (TASS for even-aged, PROGNOSIS for uneven-aged). The modelling developed case studies by using beetle risk scenarios consisting of simulated outbreaks of different frequency, intensity, and duration

Results Stand density by DBH, height, and tree age showed understorey lodgepole pine cohorts existed that did not reflect the expected "classic" even-aged stand structure, suggesting that the IDFdk1 subzone is better characterized as being "quasi" even-aged, at least in the area that stands were sampled. The presence of fire scars on overstorey lodgepole pine in the sampled stands suggest that they have experienced some low to moderate severity fires, in addition to the stand replacement and high severity fires that were responsible for stand initiation.

Gain in Knowledge Data from this work will help indicate how stands have progressed towards their present day composition and structures.

Alfaro, R.I.; Campbell, R.; Vera, P.; Hawkes, B.; Shore,T. 2004. Dendroecological reconstruction of mountain pine beetle outbreaks in the Chilcotin Plateau of British Columbia. Pages 245–256 *in* T.L. Shore, J.E. Brooks, and J.E. Stone, eds. Mountain Pine Beetle Symposium: Challenges and solutions. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Information Report BC-X-399.

Hawkes, B.; Taylor, S.W.; Stockdale, C.; Shore, T.L.; Alfaro, R.I.; Campbell, R.; Vera, P. 2004. Impact of the mountain pine beetle on stand dynamics in British Columbia. Pages 177–199 *in* T.L. Shore, J.E. Brooks, and J.E. Stone, eds. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30–31, 2003, Kelowna, British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Information Report BC-X-399.

Alfaro, R. 2009. Future productivity of lodgepole pine stands following mountain pine beetle outbreaks. FIA–FSP Project Y091087, Executive Summary.

Purpose/Study Area The analysis and synthesis of data collected from 21-year-old permanent research plots on Chilcotin Plateau (IDF and SBPS) are intended to contribute to a comprehensive understanding of stand dynamics and succession following multiple beetle outbreaks and wildfire. The results of this study will be transferred to forest managers in the form of a stand-level decision-support tool (similar to TASS-TYPSY) to visualize the implications of current and future beetle outbreaks.

Methods The project runs from 2008 to 2010. During the 1980s beetle outbreak, the CFS measured 30 stands in the Chilcotin Plateau for impacts. In 2001, 15 of these stands that survived logging and fire were remeasured for growth impacts, mortality, and succession. These stands are again infested with the beetle. Plots will be remeasured to determine changes in stand structure and regeneration, and to model future stand structure and species composition.

Results Working towards a Journal of Ecosystems and Management article.

Gain in Knowledge Little information in executive summary; interim results are on websites noted in executive summary.

Astrup, R.; Lefrancois, M-L.; Hall, E.; Coates, D. 2008. Growth and release of understorey trees in partially cut pine stands. FIA–FSP Project Y081211, Year 1 Executive Summary.

Purpose/Study Area The objectives were to:

- understand how planted, seeded and naturally regenerated interior spruce growth are affected by varying densities of pine overstorey (i.e., shelterwood system), and
- analyze the release, survival, and growth of spruce and other species in the understorey after a beetle attack to predict mid- and long-term stand dynamics and timber supply. The BEC zones are not stated.

Methods This project began April 2007 under Project Y081211; it is now Project Y092211. The 3-year project runs to March 2010. EP 591, established in 1962/63, was implemented to study naturally regenerated, seeded, and planted interior spruce performance in partially cut lodgepole pine stands with overstorey pine densities varying from approximately 0–1500 stems/ha. The experiment was established on 15 study sites with 10 different treatments consisting of:

1. 4 planting treatments comparing spring and fall planting on both scarified and unscarified sites;
2. 4 seeding treatments comparing spring and fall seeding on both scarified and unscarified sites; and
3. no seeding (control) on scarified and unscarified sites.

Today, 8 of the original 15 sites are maintained. Within the past two years, most of the overstorey lodgepole pine have been attacked and killed by the mountain pine beetle.

The initial experiment was remeasured, and a new set of plots was established to monitor regeneration ingress and the release and growth of understorey tree species other than spruce under a beetle-attacked pine canopy. The analysis of the existing remeasurements will focus on:

- the effect of overstorey structure on understorey spruce growth and survival; and
- the effect of different establishment methods on understorey spruce growth and survival.

The intent is to establish 10 new regeneration sub-plots in each of the 10 experimental plots, establish a new 15 X 15 m grid of light measurement within each plot, and tag and measure existing understorey aspen and subalpine fir (10–20 individuals per species and site). The 15 X 15 m grid will provide information on changes in understorey light levels after beetle attacks. As each plot is approximately 100 X 200 m with a 50-m buffer, the 15 X 15 m grid will yield approximately 50 light measurements per plot. Light availability will be measured by taking a wide-angle photo at each grid point and using Gap Light Index (GLI) software to determine growing season light availability summarized with the GLI light index.

Results The current year deliverables are:

- a database that combines the existing data from the earlier five measurements of EP 591; and
- remeasurement of the experiment for a total of six measurements.

They have compiled previous studies on the effects of light availability, soil preparation, and site quality on spruce germination and initial growth. The dynamics, advantages, and challenges of shelterwood systems have been reviewed.

Gain in Knowledge No report yet, so no data included in report; gains and gaps not clear.

Astrup, R.; Close, E. 2008. The effect of site type and stand structure and the relationship between growth and light availability. FIA–FSP Project Y081022, Executive Summary.

Purpose/Study Area To quantify how light availability, site type, and canopy structure influence understorey tree growth in sub-boreal forests and the influence of overstorey structure on understorey tree growth. The study builds on previous work undertaken on average site types. Study sites were located near Smithers, BC, in the Sub-Boreal Spruce Moist Cold subzone Babine Variant (SBSmc2).

Methods Project Y081022 began April 2007 and continues to March 2009. Trees were selected for sampling from five estimated light classes: 0–20%, 20–40%, 40–60%, 60–80%, and 80–100%, five site types (vegetation associations, they list only four: 02-Huckleberry–Cladonia, 01-Huckleberry, 06-Oakfern, 09-Devil's club), and five size classes: 0–80 cm, 80–160 cm, 160–240 cm, 240–320 cm, and 320–500 cm. They found these site conditions from over 50 locations in the study area, including under full forest cover, under partially cut forests, and within natural forest gaps and clearcuts.

During late summer and fall 2007, they sampled subalpine fir, interior spruce, and lodgepole pine trees and measured total height and the height growth increment for the last three growing seasons (2005–2007). Prior height was calculated by subtracting the 2005–07 height growth increments from the total height. DBH, diameter at 10 cm, crown radius, crown depth, a foliar sample, and a disk were taken from each tree. A hemispherical canopy photograph was taken. Hemispherical canopy photos were analyzed to calculate the Gap Light Index, a measurement from 0 to 100 of the percent transmission of photosynthetically active radiation above the canopy to a point in the understorey. Soil moisture regime and soil nutrient regime were assessed from soil pits near each tree. They compared 11 models for each species ranging from simple to more complex.

Results No results presented.

Gain in Knowledge No results presented at this point.

Brockley, R. 2006. Effects of intensive fertilization on timber and non-timber resources. FIA–FSP Project Y062101, Executive Summary.

Purpose/Study Area Area To learn if fertilization accelerates growth to fill timber supply pinch points after beetle attack in central and north-central BC interior within SBS, ESSF, and MS zones.

Methods This long-term research project began in 1992 at eight area-based "maximum productivity" installations (5 Pl, 3 Sx). At each site, six treatments are replicated three times for a total of 18 area-based treatment plots. The six treatments (plus control) are:

1. Control (i.e., not fertilized)
2. NB – fertilize every 6 years with (kg/ha): 200N, 1.5B
3. NSB – fertilize every 6 years with (kg/ha): 200N, 50S, 1.5B
4. Complete – fertilize every 6 years with (kg/ha): 200N, 100P, 100K, 50S, 25Mg, 1.5B
5. ON1 – yearly fertilization to maintain foliar N concentration at 1.3% and other nutrients in
6. Balance with foliar N
7. ON2 – yearly fertilization to maintain foliar N concentration at 1.6% and other nutrients in balance with foliar N

Measurements included: DBH, total height, height to live crown, leaf area index (LAI), weevil attack, and tree defence mechanisms (tree constitutive and traumatic resin canal defences, nutritive quality of leader bark, and chemical profile of volatiles from stem samples). In collaboration with Dr. S. Berch (MoFR), a fully replicated study began in 2002–03 to document the effects of 9 years of annual nutrient additions on fine root length, mycorrhizal colonization, soil microbial activity and diversity, and mesofauna abundance and community structure. In collaboration with Dr. P. Sanborn (UNBC), a study began in 1995 to examine aspects of nutrient cycling, including detailed soil sampling.

Results It's too early to reliably predict the potential impacts of intensive fertilization on harvest yields or on rotation length of managed spruce and lodgepole pine forests in the BC Interior. However, preliminary results indicate that young interior spruce plantations may be particularly well suited to "high input" silviculture. To date, the largest spruce responses are associated with the most intensive fertilization. In contrast, lodgepole pine has generally responded less favourably to large and frequent N additions. In fact, ON2 treatments have apparently caused foliar nutrient imbalances, changes in soil biota community structure and fine root attributes, and growth disruptions at some lodgepole pine study sites.

Gain in Knowledge Increasing the productivity and accelerating the development of young, managed forests is a primary objective of several timber supply mitigation strategies being developed for interior Timber Supply Areas and Tree Farm Licences. Fertilization is the best proven silvicultural treatment for increasing harvest volume and accelerating the operability of established stands, but seems to benefit some sites and harm others. Further studies are needed at these sites to quantify amino acid levels in the foliage of repeatedly fertilized trees and to examine relationships between poor growth, nutrient imbalance, amino acids, and ammonia toxicity.

Brockley, R.; Bealle-Statland, C.; van Thienen, F. 2008a. Development of residual trees and regeneration following mountain pine beetle attack in thinned lodgepole pine stands. FIA–FSP Project M086010, Final Technical Report.

Purpose/Study Area This project follows the health and growth of surviving residual overstorey, advanced regeneration and recruitment, and the longer-term fall rates of dead trees. Objectives were to describe:

- the pattern and progression of beetle attack and tree mortality;
- the growth and development of surviving residual trees; and
- the amount and type of regeneration present at the time of attack, and the post-attack ingress and development of regeneration.

Study objectives were addressed in two contrasting EP 922 field installations. One is in an older (79 years old), fire-origin stand (Takysie Lake) southwest of Burns Lake; the other is in a young (28 years old), harvest-origin stand northwest of Quesnel (Pantage Creek). The beetle attacked both trials in 2005.

A total of 11 lodgepole pine installations were distributed among four BEC zones (IDF, MS, SBPS, SBS). Stand ages ranged from 7 to 60 years when trials started. The field installations test four or five post-thinning densities (500–3000 stems per hectare) plus an unthinned control. Each treatment was replicated two or three times at each study site. A full description of the EP 922 study, including preliminary growth results from the 11 installations, is provided in Johnstone and van Thienen (2004).

Methods The Takysie Lake field experiment tests four post-thinning densities (500, 1000, 1500, 2000 sph) and an unthinned control. Each treatment was replicated three times. Treatment plots were grouped into three blocks (e.g., five plots per block), and each of the five treatments was randomly assigned to one plot within each block. The Pantage Creek trial tests five post-thinning densities (500, 1000, 1500, 2000, 2500 sph) and an unthinned control. Each treatment was replicated twice. Treatment plots were grouped into two blocks (e.g., six plots per block), and each of the six treatments was randomly assigned to one plot within each block. All trees within thinned and control plots were systematically tagged with serially-numbered tags at both study sites. At each site, growth was assessed every 5 years after the trial began. DBH was recorded for all tagged trees within each thinned plot. Height, crown length, crown width, and DBH measurements were taken from the inner 64 trees (eight rows of eight trees) within each thinned plot and from all trees within control plots. At each plot centre, three nested circular plot areas were assessed for number, species, and regeneration quality (good, medium, or poor) in different size classes.

Results Effects of post-thinning density on susceptibility of lodgepole pine to beetle attack vary with beetle population level. Amid low beetle pressure, some protection may be achieved at low stand density (less desirable microclimate) and at high stand density (less desirable DBH). Conversely, increasing tree growth and vigour by thinning may increase the risk of attack where beetle populations are high. Under these conditions, the mitigating effects of microclimate are probably minimal, and the risk of attack may be inversely related to residual stand density (largely a function of DBH). The differences in advanced regeneration abundance and features of thinning treatments at each site were not statistically significant, with the exception of higher numbers of taller advanced regeneration in the control plots; unsurprising, because the larger understorey trees were cut down in the treated plots at the time of treatment.

Differences in regeneration species and abundance were significant between the two sites but not among the treatments, with the exception of the control plots where understorey trees were not thinned out. Advanced regeneration was more abundant on warmer and moister areas. Advanced regeneration numbers don't appear to be significantly related to local stocking, seedbed

substrate, or vegetation conditions. Most treatment plots have considerable good quality advanced regeneration. However, as is typical in most partially cut stands, seedling spatial distribution is irregular and patchy.

Gain in Knowledge Despite open areas having less hospitable microclimates for beetles, thinning increases tree growth and vigour, and thus may increase desirability of trees to mountain pine beetle when populations are high. Most treatment plots have adequate numbers of advanced regeneration of good quality to contribute to midterm timber supply. However, seedling spatial distribution is irregular and patchy.

Johnstone, W.D.; van Thienen, F.J. 2004. A summary of early results from recent lodgepole pine thinning experiments in the British Columbia Interior. BC Ministry of Forests, Victoria, BC. Technical Report 016.

Brockley, R.; Bealle-Statland, C.; van Thienen, F.; Staffeldt, P. 2008b. Development of residual trees and regeneration following mountain pine beetle attack in thinned lodgepole pine stands. FIA–FSP Project M075010, Interim Report. (Interim to report above)

Burton, P.; Brooks, D. 2007. Predicting advance regeneration density in lodgepole pine stands in the northern interior of British Columbia: FIA–FSP Project Y072184, Year 2 Progress Report.

Purpose/Study Area Long-term objectives were:

- to quantify the relative influence of various site, stand, and landscape factors on the density and stocking of conifer seedlings in the understorey;
- to implement statistical relationships (derived from the above analysis) in a spatial model, predicting the density and stocking levels of conifer seedlings; and
- to train forest planners in the use of this model.

Field data collection focuses on sampling mature (> 80 years old) lodgepole pine stands in the SBSdk, SBSdw, SBSmc, SBSmk, and SBSwk subzones of the Prince George and Vanderhoof Forest Districts

Methods April 1, 2005–March 31, 2008 (old number Y061184)

Four methodological approaches were used to develop a spatial planning tool:

1. identifying, cleaning, and collating existing data on the species and density of tree seedlings and saplings in the understorey of mature lodgepole pine forests, properly georeferenced so sample locations can be mapped and analyzed through geographic information system (GIS) overlays;
2. collecting new field data to test specific site and landscape influences on advance regeneration, and to fill in the gaps of available information, again fully georeferenced;
3. statistical analysis of the above data as it relates to any and all predictive variables available in a mapped or GIS environment; and
4. incorporating results of statistical analysis into GIS scripts, macros, or other computerized tools (e.g., decision-support schema) to map and prioritize beetle-killed stands according to their expected regeneration status.

As in 2005, most sampling was arranged along transects extending from stands dominated by spruce and/or subalpine fir into stands mapped as dominantly lodgepole pine. The approach was extended into the SBSmk and SBSwk subzones (as the beetle outbreak had fully progressed into areas north of Prince George) to sample more poorer, drier and richer, wetter sites. Stand age was also targeted for more thorough representation in 2006, as older stands may have more understorey regeneration as their canopies opened. In summer 2006, most data was collected, targeting a more thorough representation of BEC subzones, site series, and age classes than achieved in 2005. The project has now sampled 564 plots, 362 of them along 58 transects in lodgepole pine stands, 121 plots in grids or clusters in near-pure pine stands, and 81 plots in 26 adjacent "seed source" stands dominated by spruce, subalpine fir or Douglas-fir. Field sampling was designed to generate a wide range of data to test the influence of BEC subzone, site series, age class, and distance from seed sources on tree seedling density and stocking. Elevation, vegetation, canopy closure, and other factors were randomly sampled and may affect tree density and distribution.

Results Of those plots dominated by more than 50% lodgepole pine (by basal area), most were in the SBSmk1, SBSdw3, SBSmc3, or SBSdk units and on 01, 03, 04, or 05 site series.

A two-way analysis of variance assessing BEC subzone and site series confirmed the significantly higher regeneration densities in the SBSwk. The preponderance of regeneration on drier (02) site series in the SBSmk and SBSwk resulted in site series having

a significant overall effect as well. The SBSdw3 seems to have a greater concentration of conifer regeneration (of all species) in stands with less lodgepole pine. The influence of proximity to non-pine seed sources seems negligible to overall conifer regeneration density. There is no consistent evidence that older stands support more advance regeneration.

When continuous and categorical variables are combined in an analysis of covariance, looking at main effects only, none of the variables examined had strong explanatory power. Of the seven variables tested, only the relative abundance of pine in the overstorey had a significant effect and explained more than 5% of the overall variance in the data set. The combined influence of ecological considerations such as stand age, subzone, and site series was little better than a purely geographical model based on the cartesian position in metres of any given stand in the study area, even though elevation is otherwise not significant as an individual factor across the study area as a whole.

Gain in knowledge Of the seven variables tested, only the relative abundance of pine in the overstorey had a significant effect on expected regeneration and explained more than 5% of the overall variance in the data set. Location had more effect than other variables.

Coates, D. 2008. Evaluation of stand dynamics after a 25- to 30-year-old MPB attack in the Flathead Region of south eastern British Columbia. FIA–FSP Project M085196, Final Technical Report.

Purpose/Study Area A retrospective study was undertaken in the Flathead in an old beetle-attacked forest to gain insight in stand dynamics post-beetle attack. No BEC zones noted.

Methods Extent of mortality, regeneration delay, release of advance regeneration and other surviving residual trees and post-beetle stand growth were determined. Five plots were established in each of 22 stands representing a range of beetle attack intensity. Pre-attack basal area varied between 29 and 58 m^2/ha. Random transects were established and plots were spaced 50 m apart. At plot centre, they used two plot sizes: a 7.99-m radius plot (for recording tree species and diameters) and a 3.99-m radius plot. Within the smaller plot, an increment core was taken from all trees larger than 7.5 cm DBH. All smaller trees were destructively sampled to obtain growth data and age. Seedlings and saplings were cut at the root collar and cross-sections were sanded. Tree rings were visually counted under the microscope to determine number of years since germination and years with possible release events were recorded. Master ring-width chronologies were developed for each site by standardization using the program ARSTAN.

Results The percent of basal area killed by beetles varied from 42 to 100%; most stands were between 60 and 80%. Six stands exceeded 80% basal area mortality and three stands were below 60% mortality. In 2007, 25 to 30 years after attack, basal area varied between 4 and 51 m^2/ha. Five stands, ranging in mortality at time of attack from 51 to 79%, had fully recovered their pre-attack stand basal area. Four stands, ranging in mortality at time of attack from 68 to 100%, had poor basal area recovery. Growth release on surviving trees exhibited species and size variability. Release of surviving lodgepole pine trees was often dramatic. Recruitment of new regeneration post-beetle attack was often, but not always, delayed by 5 to 10 years. Densities of post-beetle regeneration were often high in 2007. Based on age of understorey trees in 2007, these forests had little advanced regeneration at the time of the attack.

Gain in Knowledge

- Sites where surviving overstorey trees exhibit poor growth response had high recruitment.
- Sites with low establishment corresponded to stands with vigourous overstorey trees of either lodgepole pine or other shade intolerant species.
- With the exception of two sites where it occurred as part of a mixed stand, lodgepole pine did not establish as new individuals after beetle attack; rather, spruce and subalpine fir established.
- During the outbreak, what little advanced regeneration existed showed a good release response.

Coates, D. 2009. Evaluation of the complex stand simulation model SORTIE-ND for timber supply review in sub-boreal forests of northern BC. FIA–FSP Project Y092187, Year 1 Executive Summary.

Purpose/Study Area The study investigated capabilities and shortcomings of SORTIE-ND as a predictive model for growth and stand dynamics in sub-boreal forests (SBS mostly) of central BC, especially those affected by the beetle epidemic. Objectives for the first year of the project were to:

- evaluate SORTIE-ND for its logic and conceptual structure;
- evaluate the model's sensitivity (specific to the parameterization of the model for sub-boreal spruce forests) to uncertainty

about the parameter estimates, and to indicate the parameters with greatest influence on predictions;
- test the influence of starting condition detail (e.g., tree lists with increasing detail) on prediction outcomes; and
- determine availability and accumulate independent datasets to compare to model predictions.

Methods The 2-year project started in 2007 (under Y081187) and ran until March 2009. This report represents accomplishments during the first fiscal year, ending March 31, 2008. Model predictions will be compared to independent observations of growth from permanent sample plots (PSP) in the sub-boreal spruce zone. This will provide graphic description and summary statistics on the ranges of accuracy and precision of stand level predictions.

Results Using maximum likelihood methods and experimental individual tree growth data, five growth functions of increasing complexity were parameterized. Each growth function was used in SORTIE-ND and tested against independent data. The simplest and the most complex growth functions had the poorest predictive ability while functions of intermediate complexity had the best. This analysis has been submitted to the journal Forest Ecology and Management and is in review.

Gain in Knowledge Few conclusions presented in executive summary.

Coates, D.; Budhwa, R. 2007. Regeneration and stand structure following mountain pine beetle infestation in the sub-boreal spruce zone. FIA–FSP Project Y061148, Executive Summary.

Purpose/Study Area The project quantified tree seedling recruitment across the full range of stand types affected by mountain pine beetle. Two critical factors affecting recruitment success were assessed: abundance of parent trees and seedbed substrate favourability. Objectives were to:
- Develop, test and parameterize non-spatial recruitment models for beetle-damaged forests that can be incorporated into stand and landscape dynamics models.
- Determine the relative importance of long distance versus local dispersal.

The data cover the SBS, SBPS, and ESSF in Morice TSA, Lakes TSA, Bulkley TSA, Prince George TSA, Mackenzie TSA, and Quesnel TSA. A group led by P. Burton, CFS, Prince George, co-ordinated advance regeneration sampling. D. Cichowski added natural regeneration sampling to her sampling design of remeasured plots. In total, the three research groups established 337 natural regeneration plots across a wide gradient of site types between Houston to Prince George centred along Highway 16, and in stands with varying times since MPB attack.

Methods The project spans 2 years (2005–07). A sample site comprised two components: a "seed source" stand (a non-pine-leading stand type) and an adjacent pine-leading stand. Sample sites are selected using the following criteria:
- Presence of a seed source stand composed primarily of mature non-pine species.
- A large adjacent pine-leading stand attacked by MPB.
- No recent disturbance that would affect natural regeneration or seed tree abundance.

Sampling assessed the species composition and basal area of the seed source stand and assessed site conditions, natural regeneration, and stand structure in the pine-leading stand. Three variable radius prism plots were established in the seed source stand to characterize the species composition and abundance (basal area) of potential parent trees (seed source). A transect was established through the adjacent pine type perpendicular to the boundary between the two types. Plots were located at variable distances along the transect. Each plot in the pine type consisted of a nested set of fixed and variable radius plots established to measure all trees from seedlings to mature trees. Seedlings established post-MPB attack (natural regeneration) were identified by species and tallied in a 3.99-m radius plot. Substrate distribution was recorded within this plot and each germinant's substrate was recorded. The 3.99-m plot is also used to tally advanced regeneration (established pre-MPB attack) by species in the following classes: 0–10 cm, 10–30 cm, 30–1.3 m, and 1.3 m tall to 7.5cm DBH. Acceptability of advanced regeneration was tallied based on tree condition and each tree's expected capacity to respond to release post-MPB. A variable radius prism plot was used to record overstorey trees (> 7.5cm DBH) by species, diameter, and condition (live/dead). Co-dominant and dominant parent trees of species that are a minor component of the stand were recorded within a larger search radius around the plot centre (from 15 to 50m radius depending on parent abundance). Forest cover polygon information was recorded for the pine-leading stand and adjacent polygons to provide a measure of parent abundance that could be used for parameterization of a long distance dispersal term. Other information collected included BEC site classification and an estimate of age since attack based on overstorey condition.

Results Initial results from the first field season showed limited post-attack natural regeneration throughout the sampling area, with little regeneration of any species in younger (1–4 years) attacked stands. Natural regeneration increased in stands attacked

at least 4 years earlier. Successful establishment of lodgepole pine, interior spruce, and subalpine fir regeneration began approximately 4 years post-MPB attack. They were surprised at how common non-pine seed trees were in pine-leading stands. The original idea was to get a gradient of non-pine species parent abundance by moving away from a major non-pine seed source into a pine-leading stand, but non-pine parent trees were always close enough to provide a seed source. In general, regeneration was most successful on substrates that provide seedlings with access to consistent moisture levels and were not heavily shaded by herbs or shrubs.

Gain in Knowledge Regeneration appears to be very poor on the richer sites at all ages after beetle attack, because existing herb and shrub layers respond rapidly to improved growing conditions and shade out regeneration sites. On mesic and drier sites, regeneration begins to develop 4 to 5 years after beetle attack. They hope to refine understanding of the dynamics controlling regeneration success on these site types in the second year.

Coates, K.D.; Hall, E.C. 2006. Implications of alternate silvicultural strategies in mountain pine beetle damaged stands. Final report, FIA–FSP Project Y051161.

Purpose/Study Area SBSdk and SBSmc2. Objectives were to:

- Develop snag submodel for SORTIE-ND:
- determine light transmission values for three snag classes,
- determine snag fall down rate,
- develop code for SORTIE-ND.
- Predict understorey light environments in MPB damaged stands.
- Examine effect of beetle-killed stands on survival and growth of naturally regenerated lodgepole pine.
- Growth comparison of SORTIE-ND and TASS for complete salvage and plant prescriptions.
- Predict development of unsalvaged stand types after beetle attack.
- Determine consequences of underplanting unsalvaged stand types after beetle attack.
- Examine the implications of delaying planting in beetle-damaged stands.

Methods Using data from the BEC program to identify four major stand types found in beetle-damaged forests, they applied SORTIE-ND to 1) model development of unsalvaged stands to predict survival and growth rates of lodgepole pine natural regeneration and to 2) explore the effectiveness of different underplanting prescriptions. They incorporated a robust snag dynamics submodel into SORTIE-ND.

Results Using SORTIE-ND, they found that beetle-killed pine snags block considerable light for at least 10 years after their death. Light levels in the understorey of recently killed lodgepole pine stands are too low for pine seedlings. This is a very different regeneration environment for pine than found after wildfire.

No studies were available that track the changes in lodgepole pine snags over time with respect to either increasing light transmission or snag fall down rates. Huggard (2008a,b,c) has since contributed data. This study used three snag classes to approximate increasing light transmission of snags, recognizing that snags are continually changing. They predicted time frames for snags to move through the classes and fall based on their previous observations and those of P. Rakochy and others (i.e., no new field work).

Gain in Knowledge Beetle-attacked stands with a well-developed young spruce component recover relatively well. Within 100 years, these stands have reached merchantable size and provide a reasonable yield. Some stand types are projected to recover and become merchantable within 50 years (the *Mixed Pine–Spruce* and *Spruce–Minor Pine* types). Any salvage in these stands should target the pine while protecting the spruce. These stand types can help mitigate mid-term timber supply shortages if protected during partial salvage or left unsalvaged. However, pine-dominated stands will require underplanting or salvage and planting. Delaying underplanting for 5 to 15 years after initial beetle attack may increase survival and growth of interior spruce or subalpine fir. Delaying underplanting until pine snags transmit greater light to the understorey (5–15 years after initial beetle attack) may increase plantation survival and subsequent volume development.

Coates, D.; Hall, E.; Astrup, R. 2006. Improving juvenile tree growth prediction for complex-structured Mountain Pine Beetle damaged stands. FIA–FSP Project Y061151, Technical Report.

Purpose/Study Area For MPB-damaged areas, they developed and tested new juvenile tree growth equations that built upon previous detailed research in northern BC forests. In addition, they tested the importance of including light and size as a function

in allometry equations for small trees. The study was undertaken in the SBSmc2 and SBSdk subzones of north central BC. Study species were: lodgepole pine, interior spruce, subalpine fir, and trembling aspen. They sampled a range of sites within each subzone in order to sample across a full light gradient from low to high light.

Methods The following analyses of SBS seedling and sapling allometry were undertaken:

- DBH–Height Relationship
- Diameter 10 cm above ground (D10)–Height Relationship
- Ratio between Height and D10
- Live Crown Ratio
- Crown Diameter
- Crown Length
- Relationship of D10 to basal diameter (D0)
- Relationship of DBH to D10

Results The report presents a summary of all models tested in the allometry and growth analysis. Parameter estimates are presented for the best models only. Parameter values for other models are available from the authors.

Gain in Knowledge The improved growth and allometry functions will allow models to more accurately predict tree growth and survival across the broad range of management scenarios being practised today in beetle-damaged areas. This work is important to the development of SORTIE-ND as one of the models available to assist with the Timber Supply Review in beetle-damaged areas.

Delong, C. 2008. A framework for documenting the effects of the mountain pine beetle outbreak in sub-boreal forests of Northern B.C. FIA–FSP Project Y083072.

Purpose/Study Area The main purpose of the project is to monitor ecosystem changes over time in response to mountain pine beetle, allowing the opportunity to examine the ecological and economic benefits and tradeoffs of three potential management options: no interference, the use of prescribed burning, and conventional timber harvesting. The study takes place in the dry cool SBS, the Stuart variant of the dry warm SBS, and the Kluskus variant of the moist cold SBS.

Methods The project is long term (> 20 years) and began in 1995. As well, 50 permanent research plots are to be established in lodgepole pine-dominated stands that have been heavily impacted by mountain pine beetle within the Vanderhoof Forest District. Plots are distributed throughout unsalvaged beetle-killed stands on average sites in three common biogeoclimatic units within the SBS Zone (30 plots), dry sites (10 plots), and stands that burned following beetle attack (10 plots).

Results

- Almost complete mortality (98%) of lodgepole pine above 22 cm DBH, but variable mortality (21–98%) of smaller lodgepole pine.
- Wide variation in the density (125–7175 sph) and basal area (0.7–23.2 m2/ha) of live non-pine tree species within the stands.
- Close to 200% increase in height increment for understorey white and black spruce, and 175% for subalpine fir 2 years following death of the lodgepole pine canopy.
- 10 000–128 000 stems per hectare (mean 53 600) of newly established lodgepole pine seedlings on burned sites 2 years following wildfire.
- Slow response of understorey vegetation with slight increase in ground cover and slight decrease in moss cover.

Gain in Knowledge Wide variety of levels of live pine and release of understorey stems after attack.

(FSB) Forest Practices Board. 2007a. Lodgepole pine stand structure 25 years after mountain pine beetle attack. Forest Practices Board Special Report.

Purpose/Study Area Quesnel Forest District, 25 years after 1979 attack.

Methods Field surveys of 15 stands that met the following criteria: 1) representative of the overall forest cover, 2) at least 80% attacked, and 3) not harvested. Staff visited all of these sites and recorded the ground cover and the stand description, including species composition, the amount of dead pine, understorey regeneration species, and density and levels of coarse woody debris.

Results Fifty percent of dead trees were still standing 25 years after attack. The range of regeneration plus residuals varied from none to over 4000 stems per hectare (sph). The average total regeneration was 1600 sph. Coates et al. (2006) has suggested that 1000 stems is full stocking. Most overstorey trees that survived the infestation grew in diameter significantly faster after the epidemic than before it. Ten of the 14 sampled trees showed a significant growth response. The range of response varied from 1.0 to 3 times the radial growth than before the attack. CWD ranged from 32 to 166 m3/ha. Crown closure was at about 25%, so ECA was still about 33% indicating a slow hydrologic recovery.

Gain in Knowledge The 1979 unharvested, beetle-attacked pine stands developed a unique multi-aged and multi-sized stand structure due to the ability of lodgepole pine to regenerate under the forest canopy. This structure has considerable habitat value because it includes elements of standing wood and fallen dead trees, remnant overstorey trees, and vigorous understorey. Regarding future timber supply, there was significant diameter growth increase (release) on most residual stems; however, the standing live volume was significantly lower than volumes on comparable sites that were not attacked. Only 30% of the sites met the target of secondary structure sufficient to contribute to mid-term timber supply.

Coates, K.D.; DeLong, C.; Burton, P.; Sachs, D. 2006. Abundance of secondary structure in lodgepole pine stands affected by the mountain pine beetle. Report for the Chief Forester, August, 2006.

FPB. 2009. Biodiversity conservation during salvage logging in the Central Interior of BC. Special Report, FPB/SR/35.

Purpose/Study Area This report endeavored to answer the following questions:

- Have forest professionals responded to the Chief Forester's guidance on retention levels in large salvage blocks?
- What has been the landscape level result of salvage harvesting?

The study area was the Lakes, Prince George, and Quesnel TSAs

Methods When the project began (2007), there was no readily available map of forest harvesting. They had to create a map showing forest harvesting that had occurred up to and including 2006. When FPB compared their map of forest harvesting with the one BCMoFR later provided, they found the BCMoFR map identified only 65% of what they found—a substantial difference.

Inconsistencies in the way retention is reported in BCMoFR's Reporting Silviculture Updates and Lands status Tracking System (RESULTS) made it impossible to use the reported values to determine whether areas had actually been reserved from harvest and, if so, for what purpose.

Results They concluded that, in general, forest professionals did implement the Chief Forester's stand-level guidance on retention. On average, more mature forest structure was being left in salvage cutblocks now than before the guidance.

They also noted some very large weaknesses: There was no response to the Chief Forester's landscape-level guidance to conduct cooperative, long-term, large-scale, spatially explicit planning of harvested and retained areas during salvage harvesting. FPB emphasized the large, ongoing problem of no cooperative, spatially explicit, multi-stakeholder planning covering large areas and long time frames.

Their calculations revealed that individual cutblocks have merged with other cutblocks to create harvested areas as large as entire Landscape Units that contain very little retention. The largest of the harvested areas likely exceeds 100 000 ha as of the writing of this report. Very large (> 10 000 ha) harvested areas represent 8 to 25% of the harvested area, depending on the delineation method. These harvested areas are an order of magnitude larger than the largest harvest patch size category in the Chief Forester's guidance. Large harvested patches are, for the most part, a new phenomenon in British Columbia because of the previous cut and leave system and the old Forest Practices Code rules on cutblock size. But now cutblocks can exceed 60 ha if the harvest salvages timber damaged by fire or insects or if the patch is designed to be consistent with the attributes of natural disturbances. The extensive openings on the landscape emerged as a consequence of the accumulation of decisions about where to place individual cutblocks. Those decisions are made based on the myriad government and corporate objectives that rule the day-to-day life of professional foresters, not by planning large areas and long time frames.

They needed information about areas of mature forest within cutblocks but found government had incomplete and inconsistent records of areas retained (reserved from harvest) in cutblocks. Retention noted in plans was often not there, and some was there but not recorded. This is significant for the administration of forestry on Crown land, as there are legal requirements to report wildlife tree retention areas and not to harvest them without appropriate exemptions. Incomplete and inconsistent reporting of wildlife tree retention areas continue despite earlier assessments requesting improvement.

Gain in Knowledge They revealed some large weakness in landscape-level planning and record keeping of stand-level retention and harvest area. They made several useful recommendations advising government to take a leadership role in landscape planning and improving inventory of blocks and retention; they requested response from government by March 2010.

Green, S.; Gresbauer, H. 2006 Current/critical research on species-specific responses to climate/microenvironment change, making specific applications for MPB stands under different scenarios: Literature review. FIA–FSP Project M065004, Technical Report. (reads like an Executive Summary)

Purpose/Study Area Authors reviewed and synthesized relevant scientific literature to suggest some important differences between reforestation from advanced regeneration following mountain pine beetle attack and conventional reforestation (i.e., planting or natural reforestation following "normal" disturbance events) with regard to stand dynamics and growth.

Methods Literature review.

Results Existing literature suggests that development and yields of stands originating from advanced regeneration following beetle attack will vary greatly. Uncertainty regarding the release and growth of released advanced regeneration in unsalvaged beetle-attacked stands will complicate the capacity of forest practitioners to set management objectives and predict future yields and harvests, at least relative to even-aged silviculture or reforestation after fire.

Gain in Knowledge Relatively little. There is now empirical evidence from BC for the points they address (e.g., Burton and Brooks 2007; Coates and Budhwa 2007; FPB 2007a; Astrup et al. 2008; Coates 2008).

Hawkins, C. 2006a. Stand to landscape level effects of the mountain pine beetle (MPB) outbreak in central British Columbia. FIA–FSP Project Y06–1021, Executive Summary.

Purpose/Study Area SBSdw2, SBSdw3, SBSmc, and SBSdk southwest of Prince George. The objectives of this study are to conduct the following by age class, sub-zone, and site series:

- document beetle attack levels;
- document changes in stand characteristics of pine-dominated stands following beetle attack; and
- assess the potential of stand development after beetle attack without management intervention.

Methods This project was initiated by the UNBC Mixedwood Ecology and Management Program in June 2005 and field sampling was completed in February 2006. In total, 208 stands and 1051 TSP (temporary sample plots) were sampled. Age class 1 to 3 (young) had 92 stands, age class 4 (transitional) had 38 stands, and age class 5 to 8 (mature) had 78 stands.

Results The impact of beetle attack depended, in large part, on the stands' species composition prior to attack. Age class 1 to 3 stands were essentially pure pine; and beetle attack was primarily green and reached 30% in age class 3. As a result, these stands may not be stocked if MPB attack continues. Only 10% of the attack was green in age classes 6 to 8 but overall attack rates were about 80%. Age class 4 and 5 stands are transitional to the younger and older age classes with respect to stage of attack. On average, there was significant regeneration across the landscape but much of it was pine and very little was sub-alpine fir. There was less non-pine conifer regeneration in the SBSdk and SBSdw2 than in the SBSdw3 and SBSmc but, with the broadleaf component, these subzones were stocked.

Gain in Knowledge The author suggested it may be prudent to carefully harvest the age class 6 and 7 stands leaving all mature trees of non-pine species and the most vigorous of the saplings. He noted this will require an improvement in logging practices because the record of reversing advanced regeneration during harvesting has not been impressive in the central BC interior. However, with careful logging, these stands could provide timber both in the mid- and longer terms.

Hawkins, C. 2006b. Success rate of MPB (mountain pine beetle) attack in young stands. FIA–FSP Project M06-5002, Executive Summary.

Purpose/Study Area The objectives are to quantify the following in young age class (1 to 3) pine-leading stands of the SBSdw2, SBSdw3, SBSdk, and SBSmc biogeoclimatic subzones and site series:

- level of beetle attack;
- stand structure and composition after beetle attack; and
- amount of regeneration and its vigour and size.

Methods The project was initiated by the UNBC Mixedwood Ecology and Management Program. Sampling commenced in October 2005 and ended February 28, 2006. In total, 92 stands and 478 temporary sample plots within the Prince George Forest Region were sampled.

Results The impact of the beetle attack depended, in large part, on the stands' species composition prior to attack. Age class 1 to 3 stands were essentially pure pine; and beetle attack was primarily green, indicating an influx of mountain pine beetle to younger stands.

Gain in Knowledge Beetles were attacking young stands.

Hawkins, C. 2008. Mountain pine beetle impacts on young age class pine leading stands in the SBS Biogeoclimatic Zone. FIA–FSP Project M08-6024, Executive Summary.

Purpose/Study Area The three study areas are within the Prince George Timber Supply Area (TSA) which is divided into three forest districts: Prince George Forest District, Vanderhoof Forest District, and Fort St. James Forest District. The overarching objective of this project was to describe mountain pine beetle attack, subsequent stand dynamics, and to develop sound post beetle management scenarios for stands of all age classes. Desired outcomes supporting this were to quantify and map the composition and structure of forests in a post-mountain pine beetle environment. Objectives were:

- Quantify stand and forest change and dynamics following beetle attack in SBS subzones.
- Quantify the beetle's impact on mid- and long-term timber supply (age classes 2, 3, and 4) in different SBS subzones with "real time" data for the beetle's effects.
- Document residual stand development under different levels of beetle attack and advanced regeneration.
- Prepare cost–benefit analysis of restoration strategies in the SBS for different levels of beetle attack and advanced regeneration.

Methods This project used data collected by the previous research projects (M065002 Success rate of MPB attack in young stands; Y061021 Stand to landscape level effects of the MPB outbreak in central British Columbia; CFS MPBI 8.23 Stand level effects of the mountain pine beetle outbreak in the central BC Interior; CFS MPBI 8.59 Temporal composition and structure of post-beetle lodgepole pine stands: Regeneration, growth, economics, and harvest implications). By linking the data collected in these four projects, the duration of M08-6024 spans 2005–08 and encompasses the three large sampling areas noted above.

Data collected in each temporary sample plot (TSP) were: crown closure using a spherical densitometer, and, for trees > 7.5 cm DBH: species, vigour, DBH, stage of attack, relative crown position (dominant, codominant, etc.), and wildlife-danger tree classification. Height was taken for the site index tree (SI50) in each plot. A smaller plot with the same plot center as the larger mature tree plot was used to collect regeneration or secondary structure (natural or artificial) information in each TSP.

Results Their repeat survey data showed that attack surges when the population arrives in the area, it then spreads into adjacent immature stands, where it fails to reproduce, which ends the outbreak in that area. Mountain pine beetle attack in age classes 2, 3, and 4 was much higher than originally anticipated and assumed in the Prince George TSA timber supply review.

Gain in Knowledge Although the majority of immature stands at the landscape level have adequate secondary structure to be considered stocked, some of these stands may result in mixed broadleaf–conifer forests. Their SORTIE-ND modelling scenarios suggest that the best option for immature stands may be to allow the stand to develop naturally without intervention and harvest. This allows them to contribute to the mid-term timber supply. Underplanting appears to only be successful at extreme levels of attack, greater than 90% (due to light levels). Highly variable stand characteristics found in their study suggest that restoration activities and/or management strategies that are cost-effective and environmentally sound should be selected on a stand-by-stand basis.

Hawkins, C; Runzer, K.: Balliet, N. 2009. The release of secondary stand structure in immature and mature pine stands following mountain pine beetle attack. FIA–FSP Project Description.

Purpose/Study Area Since 2004, Hawkins group has conducted beetle-attack surveys in approximately 525 polygons: 235 in immature (age class 1 to 3); 80 in transitional (age class 4); and 210 in mature stands (age class 5 to 8). Study areas are located in the southern portion of the Lakes Timber Supply Area (TSA), and the southwest, southeast, and west–central portions of the Prince George TSA (likely mostly SBS). The survey data, collected in previous mountain pine beetle research projects, allows description of beetle attack and stand structure, quantification of regeneration by stand attributes, and tree lists for use in stand-level growth

and yield models. A temporal component has been added for stands initially surveyed in 2005 and 2006. This project will use stands initially sampled in 2005 and 2006. The focus will be on age class 2 to 4 (21–80 years) stands, with a lesser emphasis on age class 5 to 8 (81–250 years) stands. Stands with moderate to high levels of beetle attack will be the study focus.

Methods This project considers six forest management questions identified by industry and government:

1. What is the quality and quantity of regeneration in beetle-affected stands?
2. What are the growth and yield implications of treating or leaving beetle-attacked stands and letting the secondary stand structure develop?
3. What is the release potential of these stands?
4. Which trees will release and when?
5. What are the economics of treating or leaving beetle-attacked stands with varying amounts of secondary stand structure?
6. What are the medium- and long-term impacts of residual and secondary structure on timber supply?

Several SORTIE-ND simulations will be conducted for each sampled stand:

- leave the stand alone;
- underplant the attacked stand;
- remove only the pine;
- remove the pine and under (fill) plant; and
- clearcut or clear the stand and plant. Each scenario also includes an economic analysis.

Results None yet.

Gain in Knowledge The findings are intended to improve harvest scheduling, identify stands most suitable for retaining or restoring, and guide stand activities that positively affect the growth and quality of secondary stand structure.

Hawkins, C.; Rakochy, P. 2007. Stand-level effects of mountain pine beetle outbreak in the central British Columbia Interior. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2007-06.

Purpose/Study Area Pure pine stands were sampled in the SBSdk and pine-leading stands in the SBSdw2, SBS dw3, and SBSmc3 in the central BC Interior to document changes in stand characteristics of pine-dominated stands following beetle attack and assess potential of stand development after beetle attack without management intervention.

Methods They sampled 48 stands and more than 300 plots in SBSdk; 74 stands and more than 370 plots in other SBS variants in 2004.

Results About 5% of trees less than 10 cm DBH were attacked, and attack rates exceeded > 80% for DBH > 20 cm. On average there were 328 stems per ha of healthy regeneration in SBSdk: about 200 were seedlings and 128 were saplings; 45.7% pine, 38.4 spruce, 10.1% subalpine fir, 5.3% aspen. In SBSdw and SBSmc there were 2003 sph of healthy regeneration of which 1173 were seedlings and 830 were saplings. The beetle attack created uneven-aged or complex stands in the age classes sampled. The authors suggest that competition between seedlings and shrubs and herbs is less on drier sites, so seedlings may release well except on the wettest sites. Attack rates increased with stand density. Species composition before and after beetle attack is summarized in Table 1 (below).

Gain in Knowledge The extent of impact from the beetle depends on pre-attack stand composition. Pure pine stands had the least stocking after attack, pine-leading stands were well stocked after (with pine and non-pine species). Regeneration was poor in pure pine, at least in 2004 (but better in 2005). Without intervention, stands in SBSdk will not likely produce mid-term timber supply. SBSdw2, SBS dw3, and SBSmc3 stands were well stocked and do not require intervention. There was sufficient regeneration in the SBSdw and SBSmc to consider a stand fully stocked even if all live pine were to die. Vigourous young stands were at greater risk than previously believed.

Table 1. Species composition (percent) overall and by age class before and after attack by the MPB in the SBSdw, mc and SBSdk.

	Species*	Overall	Age Class 5	Age Class 6	Age Class 7	Age Class 8
Pre-MPB						
SBSdw, mc	Aspen	1.23	1.60	0.28	1.70	1.36
	Sub-alpine Fir	2.14	0.75	4.45	2.73	0.34
	Birch	1.40	1.69	1.42	2.26	0.00
	Douglas-fir	6.80	7.25	5.02	7.63	7.37
	Pine	61.83	69.77	67.71	50.24	59.18
	Black Spruce	7.21	10.45	1.61	3.96	13.95
	Hybrid Spruce	19.38	8.47	19.51	31.48	17.80
SBSdk	Aspen	0.16		0.00	0.18	0.19
	Sub-alpine Fir	0.11		0.00	0.13	0.10
	Pine	92.98		95.87	94.37	88.54
	Hybrid Spruce	6.75		4.13	5.33	11.17
Post-MPB						
SBSdw, mc	Aspen	2.31	2.85	0.59	2.90	2.75
	Sub-alpine Fir	3.89	1.34	9.25	4.52	0.23
	Birch	2.64	3.02	2.95	3.87	0.00
	Douglas-fir	12.63	12.73	10.43	12.90	14.65
	Pine	29.46	47.07	33.27	16.29	19.68
	Black Spruce	13.46	18.43	3.35	6.61	28.15
	Hybrid Spruce	35.62	14.57	40.16	52.90	34.55
SBSdk	Aspen	0.45		0.00	0.52	0.57
	Sub-alpine Fir	0.30		0.00	0.39	0.29
	Pine	81.24		91.00	84.41	68.38
	Hybrid Spruce	18.01		9.00	14.69	30.77

*dead trees from other causes are not included in the summary.

Hawkins, C.; Balliet, N. 2009. Regeneration and growth following MPB attack: Synthesis of knowledge. FIA–FSP Project G095048, Executive Summary.

Purpose/Study Area Summarize the knowledge gathered by the many recent mountain pine beetle research projects and identify the knowledge gaps on regeneration and growth following beetle attack. This information should be available to practitioners, managers, and researchers for:

- using research in management decisions (forecasting the long-term prospects of these stands; selecting stands for silvicultural treatments to improve yield; and forecasting impacts to hydrology, habitat, and vegetation types as a result of beetle attack);
- identifying research needs; and
- prioritizing further research in this area.

Also, data must be documented before this information is lost. Studies collectively cover all BEC zones affected by the beetle.

Methods Literature review. This work synthesizes key findings and knowledge gaps from regeneration (secondary structure) projects funded by FSP and MPBI.

Results This project began April 1, 2008, and is scheduled to end March 31, 2010; results are preliminary.

Gain in Knowledge So far it appears that the ability to predict species mixes and amounts of secondary structure is limited at best. Existing regeneration varies greatly.

Huggard, D. 2008a. Projected performance of seedlings planted under mountain pine beetle stands. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC.

Purpose/Study Area To combine previously synthesized information on growth rates of seedlings under partial canopy and projected light levels under beetle-affected stands over time, and to project growth of seedlings planted under beetle-killed stands at different times after attack. Synthesis encompasses several BEC zones.

Methods Growth is projected for four species (lodgepole pine, Engelmann/hybrid spruce, subalpine fir, Douglas-fir) in modelled stands that vary in factors affecting growth or light conditions: site index (10, 15, 20, 25 m at 50 yr), mean diameter of the beetle-killed stand (10, 25, 40 cm), the stand's light levels before the beetle (10%, 30%, and 50% of above-canopy light), non-pine species component of the overstorey (0, 20, and 40%), and for seedlings planted just after the overstorey pines die, or 5, 10, 15, or 20 years later.

Results The synthesis predicts that seedlings underplanted in typical pure mature pine stands (25cm average DBH, 30% initial light) that have been killed by the beetle will be delayed 5 years (lodgepole pine) or 3 years (other species) in height growth and 9 years (lodgepole pine) or 6 years (other species) in diameter growth. This response includes the initial effects of shading in the recently killed stand and the diminishing effects as the dead pine decay and fall.

A more important factor is the mortality of the underplanted seedlings. Existing empirical information on survival of planted seedlings versus light level under partial cover is very limited. Best guesses at this point suggest substantial mortality with immediate planting in dense stands, and moderate mortality in typical, or more open, stands. A 5-year planting delay would reduce this mortality, but at least a 10- or 15-year delay is needed to lower mortality rates to levels similar to those of open-planted seedlings. These projections are based on results from only three studies, and factors such as size and quality of the planting stock and quality of site preparation and planting undoubtedly have large effects on the survival of underplanted trees.

Gain in Knowledge Operationally, this may support quicker underplanting in more open beetle-affected stands, and where species other than pine are being replanted. For dense stands and where pine is the favoured species for planting, delaying planting until the decaying stand is moderately open would have little additional effect on delaying growth, and may avoid high initial mortality. Collecting basic information on seedling survival and light levels is simple (and quicker than growth measurements), and should be incorporated into any operational underplanting of beetle-killed stands.

Huggard, D. 2008b. Predicting light interception in decaying MPB stands. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC.

Purpose/Study Area To predict interception of light by lodgepole pine trees killed by mountain pine beetles as these dead trees decay and fall.

Methods The analysis combines information on fall and breakage of snags (from many sources), and loss of shading by branches and dead foliage (mainly from work by Coates and Hall 2006), along with estimates of the uncertainty of these parameters.

Results See Huggard 2008c and 2008a in section 8.2 for more details on results. The results are for stands composed entirely of lodgepole pine that have been killed by mountain pine beetle. For stands with a live non-pine species component of the overstorey, the shading from those trees could be assumed to remain constant. The curves in Figure 6 of the report could simply be scaled down so that they asymptote x% lower, where x is the percentage of non-pine overstorey.

The predicted shading trajectories are stand averages. In reality, patchiness would produce variability in light (including in the green stand), which probably matters for seedling survival and growth.

Gain in Knowledge The report provides estimates of light through dead canopies. Because light interception by foliage and branches dominates shading trajectories, this is the most important component for collecting additional data. That should include variability in both the transmission of each snag class and the ages of the snags in the classes.

Two more factors to consider in incorporating the effects of live non-pine overstorey are: 1) Light interception likely varies by species. For example, a 30% live Douglas-fir component in a beetle-killed pine stand might actually intercept 50% of the light (if the firs are bigger than the pines, or bigger- and deeper-crowned). 2) The non-pine overstorey likely responds to increased light levels as the pine die and decay. The non-pine overstorey would therefore intercept more light over time, which would require more detailed stand modelling.

Huggard, D.J.; Kremsater, L.L. 2007. Quantitative synthesis of rates for projecting deadwood in BC forests. FIA–FSP Project SO84000, Technical Report.

Purpose/Study Area Authors provide a quantitative synthesis of the published technical literature on parameters needed to project deadwood habitat in BC conifer forests, including rates of snag decay, breakage and fall, and coarse woody debris (CWD) decay. Many BECs are treated.

Methods They outline how these parameters are used in a detailed dead wood projection model they developed. Additional information is provided by an extensive analysis of 5-year fates of tagged trees and snags in a large habitat monitoring program in variable retention cutblocks and uncut stands, conducted by Weyerhaeuser and Western Forest Products in coastal BC.

Results They present rates of snag fall, breakage, and transition between decay classes, and decay of downed wood.

Gain in Knowledge Useful synthesis of many studies on snag fall and CWD decay.

Jackson, S.; Campbell, E. 2009a. Assessing the threat of mountain pine beetle outbreaks to whitebark pine in British Columbia. FIA–FSP Project M08-6048, Final Technical Report.

Purpose/Study Area The objectives of the project were:

- to map climatically suitable habitat for mountain pine beetle over the range of whitebark pine in BC and assess the potential impacts of climate change;
- to describe stand structure and reconstruct disturbance history and stand dynamics (including whitebark pine population dynamics);
- to assess natality (fecundity and development), mortality and voltinism (life cycle duration) of mountain pine beetle on whitebark pine;
- to initiate a study of whitebark pine defences to beetle attack.

Methods Authors modelled suitable beetle climates and compared those to whitebark pine ranges. They documented infestations per year in parts of the whitebark pine range previously considered climatically unsuitable. Two of the nine stands surveyed (Tweedsmuir and Cranbrook) were chosen to conduct detailed stand dynamics studies that included tree age determinations through coring, and mapping of each tree taller than 1.3 m. Stand dynamics in other stands were inferred from tree diameter class distributions. For more than 10 whitebark pine trees attacked each year, they recorded attack densities, stages of beetle development, and the size of populations emerging from the north and south sides of whitebark pine trees. Bark samples were taken back to the CFS laboratory in Victoria to verify attack densities, measure the timing and size of emerging populations, assess survivorship by developmental stage, identify causes of beetle mortality, measure egg gallery length and larval gallery abundance/female fecundity. Stands were sampled in 2006 and revisited in 2007.

Results They presented results site by site in some detail. Mountain pine beetle is currently killing a large proportion of all the whitebark pine in the stands sampled. In dense stands, where understorey regeneration is low, the beetle outbreak is or will accelerate the successional process and eliminate whitebark pine from these sites. On more open sites, where regeneration is less susceptible to the beetle, whitebark pine is unlikely to be eliminated. However, major reductions may still have important negative impacts: whitebark pine populations below a certain point mean that the main disperser of whitebark pine seed, Clark's nutcracker, may move to other regions where seed is more abundant, reducing the number of seed dispersers. Moreover, many small whitebark pine are infected by blister rust. On the positive side, a small proportion of whitebark pine were able to resist beetle infestations.

Gain in Knowledge Mountain pine beetle is killing a large proportion of whitebark pine in each sampled stand. A small proportion resisted attack. Reduction in whitebark pine may affect Clark's Nutcracker.

Jackson. S.; Campbell, E. 2009b. Assessing the threat of mountain pine beetle outbreaks to whitebark pine in British Columbia (2 year project 2007–2008). FIA–FSP Project M07-5048, Technical Report, Preliminary Results. (preliminary results of study above)

Kremsater, L.; Dunsworth, G.; Vyes, A.; Murray, C. 2009. Forests for Tomorrow adaptive management initiative: Synthesis of information on selected topics and clarification of key uncertainties. Report to BC Forests for Tomorrow.

Purpose/Study Area To summarize information on topics raised by Forests for Tomorrow recipients. Many locations.

Methods Literature review of: impact of falling (dead) trees on seedling survival; overstorey release in response to light; managing snowshoe hare damage; viability of seed from dead lodgepole pine; response of BC conifers to light conditions created by overstorey mortality or removal; management of pine grass competition; effect of the dwarf mistletoe on regeneration in beetle-killed lodgepole pine stands; effects of stems rusts and a stem canker on regeneration in beetle-killed lodgepole pine stands; and risk of fire after mountain pine beetle.

Results The review summarizes reports related to all the above topics. A major topic is the summary of overstorey release and understorey responses to light and subsequent response of understorey shrub and grasses post-beetle.

A qualitative assessment of the few studies found suggests that overstorey lodgepole pine and interior Douglas-fir may increase in crown size by 30 to 40% over 5 years in stands after beetle attack. Similar increases in stem diameter will occur, increases in height are likely not significant. Shading may be increased as much as 10 to 20% near live trees over 5 years as a result of the expanding crowns. At the same time, light levels are increasing due to dying twigs and branches, so the net light levels are not simple to estimate. The proportion of live trees in the stands will determine the net changes in light levels. Empirical studies to assess changes in light and crown closure over time for various combinations of proportion of live and dead stems in a stand would be informative.

Regarding understorey tree responses:

- All species, even ones that tolerate shade, grow best under full sunlight.
- Shade-tolerant species (e.g. western hemlock, western redcedar, subalpine fir) grow well under low light and relatively poorly, compared to other species, under high light.
- Shade-intolerant trees, especially lodgepole pine, can grow (more so in height than diameter) under low light once they are established, but will likely not survive well.
- Shade-tolerant species have a strong capacity to adjust carbon assimilation, slow or stop growth, and reallocate carbon to allow both persistent and rapid response to decreasing or increasing light conditions.
- Size and vigour significantly affect light responses across species.
- Shade-tolerance response appears to be relatively consistent across the regions in BC
  - There are relatively small differences in light response curves among species with the exception of Pinus species.
  - Species choice for light response appears to be least important in the ICH Biogeoclimatic Ecosystem Classification (BEC) variant.
  - The strongest response to increasing light was in moderate and moist climates like the ICHmc (particularly for hybrid spruce and subalpine fir).
  - Growth under low light may be enhanced in cold climates such as the ESSFmc and ESSFwv for hybrid spruce and subalpine fir.
- Underplanting is a useful option, but requires overstorey manipulation and creation of light environments that balance the species tolerance needs with the competitive response of vegetation.

Pinegrass cover increases quickly and dramatically in response to greater light provided by harvested openings greater than one tree length in diameter. Following clearcutting, dense stands of pinegrass can develop within 2 to 4 years. Lightly disturbed areas can be completely invaded after one season. Severely disturbed areas are usually invaded after 4 to 5 years. The grass is increasing under the light levels found under dead pine stands but it is not clear how much competition occurs and how competition develops over time

Gain in Knowledge Literature summary and general guidelines for all topics noted above.

LeMay, V.; Lee, T.; Sattler, D.; Marshall, P.; Robinson, D.; Zumrawi, A. 2007. Modelling natural regeneration following mountain pine beetle attacks in the southern and central interior of British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2007-16.

Purpose/Study Area The model, SORTIE-ND, was tested in the first year of this project as a possible means of obtaining dynamic estimates of regeneration to add to PrognosisBC. However, this method requires detailed information on recruitment and survival. Another approach is to introduce regeneration and saplings at a fixed point in the future, when all responses to the disturbance have occurred. Because a number of species and sizes can be present in this list of regenerated trees, including saplings, the challenge becomes estimating these species and sizes simultaneously. A multivariate estimation approach can be used to obtain logical consistency across species and size classes. The focus of this research is to apply the second approach to abundance and composition of natural regeneration (and saplings) for several years following attack.

Specific objectives were:

- to assess natural regeneration development in stands that have sustained mortality during current and/or previous beetle outbreaks;
- to develop a natural regeneration database to use with the PrognosisBC growth and yield simulator;
- to use imputation techniques to extend the existing natural regeneration model to beetle-affected stands in the southern and central interior of the province; and
- to develop and enhance the software necessary to allow reasonable projections of beetle-affected stands.

Table 2. Number of plots by BEC zone and data source (combined data).

BEC Zone	CFS Data	FSD Data	Total
IDF	80	58	138
SBPS (SBPS & SBS)	75	113	188
Total	155	171	326

Methods Data included CFS data and UBC data (FSP data collected in the summer 2006) from three BEC zones in central BC (see Table 2 above). The CFS data consisted of overstorey and understorey trees in plots measured shortly after attack and again 14 years later. The FSP data were collected in stands that had been attacked by mountain pine beetle a number of years earlier (approximately 25 years earlier for most of the plots). Fourteen overstorey variables were selected for estimating regeneration by species and size classes using multivariate nearest-neighbour imputation.

Results Based on plot data noted above, the average amount of regeneration per hectare was quite high, and included predominantly pine and deciduous species, with few other conifers. Only three of the 326 plots had no regeneration. As to pine regeneration, 42% of the plots in IDF, and 37% of plots in SBPS/SBS had no pine regeneration, most of these being plots 16 years after disturbance. As to non-pine conifer regeneration, 45% of the plots in IDF, and 64% of plots in SBPS/SBS had no other conifers. Deciduous species did not regenerate in 19% of the IDF and 40% of the SBPS/SBS plots.

The number of saplings, all species combined, declined over time. Pine saplings decreased; but seedlings showed no consistent trend. Seedlings and saplings of other species increased or were the same over time. The number of saplings, all species combined, increased with a decrease in overstorey trees for both IDF and SBPS, particularly with a decrease in stems and basal area per ha of standing dead trees. Seedlings did not show a consistent increase or decrease in response to changes to the overstorey stems and basal area per ha. Because sapling survival and growth is dependent upon growing space and light, saplings responded to overstorey mortality and subsequent falling of snags. Seedling establishment was restricted by fallen snags, because of reduced substrate availability.

Simple correlations between each regeneration variable a number of years attack (8, 16, or 25 years) and each overstorey variable shortly after attack indicated moderate positive correlations between regeneration of non-pine coniferous trees and the stems per ha and basal area per ha of the non-pine conifers. For both IDF and SBPS/SBS zones, there was a low negative correlation between non-pine species regeneration and pine overstorey stems per ha. Pine regeneration was positively related to elevation and negatively related to stems and basal area per ha of non-pine conifers. Deciduous regeneration was negatively correlated with non-pine overstorey in IDF. Non-pine conifers were positively correlated with competition as measured by crown competition factor (CCF), whereas pine and deciduous trees were negatively related. Correlations with other individual overstorey variables, including the stems per ha, quadratic mean diameter, and basal area per ha of pine snags were generally very low.

The authors include a useful literature review on regeneration under dead pine, including that of Heath and Alfaro (1990) who examined the growth response of residual trees in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the beetle in the Cariboo Forest Region of BC. Heath and Alfaro observed that the beetles killed mainly the large diameter lodgepole pine trees in the stand, and therefore described this as a type of thinning from above; their study showed that even though 76% of the lodgepole pine trees were killed during the beetle outbreak in the study area, all the Douglas-fir and a large proportion of the remaining lodgepole pine trees responded to the beetle-induced thinning with a diameter growth increase which persisted 14 years after the infestation. Annual diameter growth rates of Douglas-fir in the post-outbreak period averaged 2% per year without the beetle-induced thinning and 2.9% following thinning. For the surviving lodgepole pine trees, the annual diameter growth rates doubled from 0.4% per year.

Gain in Knowledge This study indicates regeneration following beetle attack varies considerably, particularly over space, with only three plots showing no regeneration. Most plots had pine regeneration, mixed with deciduous regeneration, and some non-pine regeneration. There is some possibility of populating PrognosisBC with these data.

Heath, R.; Alfaro, R.I. 1990. Growth response in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle: A case study. Journal of the Entomological Society of BC 87:16–21.

[LeMay et al (2007) includes a useful literature review: Hawkes et al. (2004) conducted a 3-year study to examine the impact of mountain pine beetle on stand dynamics in BC. Pine stands in the Chilcotin Plateau, Kamloops and Nelson Forest Regions, Entiako Protected Area, Manning Provincial Park, Kootenay National Park, and Bull Mountain were sampled. Selected stands were dominated by lodgepole pine, mixed with interior Douglas-fir, spruce, and other species. Data were gathered from direct field measurement and PSP records. Increment cores were collected in the plots and ring widths measured to construct chronologies. Results indicated that post-outbreak, standing live tree volume and density were reduced by 22% and 36% respectively, with differences in stand structure creating considerable variation. They observed that effects of the beetle on forest stand dynamics resembled those of defoliating insects, which are known to improve the growing environment of surviving trees following an epidemic attack because more resources become available to fewer trees (e.g., mortality of lodgepole pine after an beetle epidemic permits the accelerated growth of small Douglas-fir and spruce trees or seedlings; Hawkes et al. 2004). This suggests a shift towards shade-tolerant species over the long term. A similar pattern was reported by Veblen (1991) following windthrown lodgepole pine-dominated stands in Colorado, USA. Accelerated growth observed in stands following beetle attack contrasts with disturbance by high-intensity fires where few trees survive, leading to complete or nearly complete stand renewal.

In thinned stands, Mitchell and Preisler (1998) reported it took up to 3 years after the attack before dead pine trees began to fall; 50% of dead trees had fallen after 8 years; and 90% trees had fallen after 12 years. In unthinned stands, the process was slightly slower, with some dead trees falling after 5 years, 50% of dead trees falling within 9 years, and 90% falling within 14 years. Generally, the time to fall-down depended on local environmental factors.

Several studies have examined understorey vegetation following beetle attack. Kovacic et al. (1985) studied understorey biomass in ponderosa pine after attack, and reported that mortality of trees following attack was similar to thinning impacts and that understorey biomass peaked at 5 years after attack. Heath and Alfaro (1990) summarized stand conditions before and after beetle attack for a mixed stand in the Cariboo Forest Region of BC. Before the outbreak, the stand overstorey had about 560 stems per ha consisting of 80% lodgepole pine, 19% interior Douglas-fir, and 1% white spruce. The understorey vegetation of 3190 small trees per ha was comprised of 90% interior Douglas-fir, 5% lodgepole pine, and 5% white spruce. About 76% of pine trees were killed by the beetle. Fourteen years after the first measurement, the number of interior Douglas-fir and white spruce in the overstorey increased. However, the composition of the understorey vegetation of 2698 trees per ha resembled that prior to the beetle attack, with 91% interior Douglas-fir, 7% lodgepole pine, and 2% white spruce. They concluded that beetle attack affects the composition of tree species in the overstorey more than in the understorey.

Stone and Wolfe (1996) found the amount of understorey biomass depended on the mortality rate of overstorey lodgepole pine. Murphy et al. (1999) examined the response of advanced lodgepole pine regeneration to overstorey removal in eastern Idaho following salvage logging 15 years after beetle attack. The lodgepole pine regeneration significantly increased in growth rates 3 years after salvage logging.

Examining regeneration following beetle outbreak in the Chilcotin Plateau, BC, Hawkes et al. (2004) observed that lodgepole pine had the highest rate of regeneration, followed by species such as Douglas-fir, spruce, and subalpine fir in the year immediately following an epidemic. Four years later, sub-alpine fir had disappeared while trembling aspen and willow had regenerated. Stockdale et al. (2004) obtained results similar to those reported by Hawkes et al. (2004).

Zumrawi et al. (2005) used the PrognosisBC regeneration sub-model to predict regeneration in beetle-affected stands.

Cichowski, D.; MacLean, N. 2005. Tweedsmuir–Entiako caribou population: Technical background information summary. Prepared for BC Ministry of Environment, Smithers, BC.

Hawkes, B.; Taylor, S.W.; Stockdale, C.; Shore, T.L.; Alfaro, R.I.; Campbell, R.; Vera, P. 2004. Impact of the mountain pine beetle on stand dynamics in British Columbia. Pages 177–199 in T.L. Shore, J.E. Brooks, and J.E. Stone, eds. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30–31, 2003, Kelowna, British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Information Report BC-X-399.

Kovacic, D.A.; Dyer, M.I.; Cringan, A.T. 1985. Understory biomass in ponderosa pine following mountain pine beetle infestation. Forest Ecology and Management. 13(1/2):53–67.

Murphy, T.E.L.; Adams, D.L.; Ferguson. D.E. 1999. Response of advance lodgepole pine regeneration to overstorey removal in eastern Idaho. Forest Ecology and Management 120:235–244.

Mitchell, R.G.; Preisler, H.K. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. Western Journal of Forestry 81:598–601.

Stockdale, C.; Taylor, S.; Hawkes, B. 2004. Incorporating mountain pine beetle impacts on stand dynamics in stand and landscape models: a problem analysis. Pages 200–209 *in* T.L. Shore, J.E. Brooks, and J.E. Stone, eds. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30–31, 2003, Kelowna, BC. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Information Report BC-X-399.

Stone, W.E.; Wolfe, M.L. 1996. Response of understory vegetation to variable tree mortality following a mountain pine beetle epidemic in lodgepole pine stands in northern Utah. Vegetation 122(1):1–12.

Veblen, T.T.; Hadley, K.S.; Reid, M.; Rebertus, A.J. 1991. The response of subalpine forests to spruce beetle outbreak in Colorado. Ecology 72:213–231.

Zumrawi, A.; LeMay, V.; Marshall, P.; Hassani, B.T. 2005. Implementing a PrognosisBC regeneration sub-model for complex stands of southeastern and central British Columbia. FII Project R2003-165.]

Marshall, P.; Lemay, V.; Coates, D.; Zumrawi, A-A. 2008. Modelling natural regeneration in MPB-impacted stands. FIA–FSP Project MO86015, Final Report.

Purpose/Study Area 2006 sampling was near Williams Lake, 2007 sampling near Kamloops, in the IDF and MS BEC zones.

Methods LeMay et al. 2007 (above) used year 1 data from this project. Overstorey, small tree, and regeneration plots were established and measured in stands then used in a calculation (most similar neighbour calculation to grow trees back) to estimate live and dead trees and regeneration shortly after beetle attack, then input into PrognosisBC. These data are also used in the light-driven model SORTIE-ND (Sattler et al. 2008, below).

Results Natural regeneration varies greatly and models will remain relatively imprecise.

Gain in Knowledge This approach and model best used as average across a region, not to predict specific sites.

Marshall, P.; Lemay, V.; Coates, D.; Zumrawi, A-A. 2007. Modelling natural regeneration in MPB-impacted stands. FIA–FSP Project MO75015, Executive Summary.

(Executive summary of LeMay et al. 2007 above – Modelling natural regeneration following mountain pine beetle attacks in Southern and Central Interior of British Columbia).

Nigh, G.; Parish, R.; Antos, J. 2007/2008. Density and distribution of advance regeneration in the MS biogeoclimatic zone in relation to site moisture and overstorey density. FIA–FSP Projects M075001, M086001.

Purpose/Study Area Extensive stands of mature lodgepole pine occupy the plateaus in the Montane Spruce zone in the Merritt Timber Supply Area. For the MS zone, information is inadequate for assessing whether advance regeneration has the potential to form new stands of economically acceptable characteristics within an acceptable timeframe. This project provides forest managers with a decision support tool to help them determine whether a stand can be left to regenerate naturally, requires fill planting, or requires rehabilitation.

Methods Authors established sample plots in 28 stands vulnerable to or under attack (green and red attack). Sampled stands were mature and had at least 70% lodgepole pine. Samples were sorted into three strata based on site moisture: wet, mesic, and dry relative to the range of sites with lodgepole pine. Sampling aimed at obtaining a similar number of stands in each stratum. Each sample location had 40 quadrats, each 5 X 5 m, in a 5 X 8 grid of contiguous quadrats. The following measurements were taken in each quadrat: count of all advance regeneration trees by species and height class (commercial species only); height, diameter at breast height (DBH), species, and attack status of all trees (commercial species only). Advance regeneration height classes were: < 0.1 m, 0.1–0.3 m, 0.3–1.0 m, 1.0–2.0 m, 2.0–10.0 m. Trees taller than 10.0 m were overstorey trees.

Results Summary statistics for the 28 sample plots are presented. The abundance of tree species is shown in two tables (by height class and by moisture class). Regeneration in each subplot varied, ranging from 0 stems per hectare to overstocked. Attack status of trees was highly correlated to tree height.

Gain in Knowledge The amount and pattern of regeneration may be used in growth and yield models such as Tree and Stand Simulator (TASS) and Table Interpolation Program for Stand Yields TIPSY to predict the growth and composition of future forests.

Runzer, K.; Hassegawa, M.; Balliet, N.; Bittencourt, E.; Hawkins, C. 2008. Temporal composition and structure of post-beetle lodgepole pine stands: Regeneration, growth, economics, and harvest implications. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-23.

Purpose/Study Area The study took place in the Prince George TSA during 2005, 2006, and 2007. The objectives were to quantify the composition and structure of forests in
a post-beetle environment; specifically to:

- investigate temporal and spatial aspects of mountain pine beetle attack;
- investigate regeneration dynamics (mortality and growth) of post-beetle attack;
- model growth and yield with actual mortality and regeneration metrics;
- describe economic opportunities of harvest scheduling with respect to post-beetle stand structure; and
- improve management and regeneration options.

Methods During 2005, 2006, and 2007, temporary sample plots (TSP) were established based on candidate stands identified from forest cover maps in the Prince George TSA. Sample stands were identified as lodgepole pine-leading, age class 1 to 8, 0 to 9 years since green attack, SBS BEC zone, less than 1 km from an access point, and on mesic and sub-mesic site series. Seventy percent of stands were randomly selected and 30% were systematically selected to ensure complete coverage of age classes and various stand attributes. The forest simulator model SORTIE-ND was used to project the outcome of four management scenarios:

1. the base case: stand development without beetle attack (Base);
2. the result of beetle attack: attacked trees proportionally removed by 2 cm DBH classes;
3. underplant the beetle-attacked stand and let the residual tree layer and secondary structure develop; and
4. clearcut the tree layer and replant with 800 sph of spruce and 800 sph of pine.

Concerns with the no-treatment option are fire hazard, species composition, release rate of secondary structure, and stand density. Concerns with underplanting are its costly and frequent failure due to abiotic and biotic agents. Concerns with the clearcut scenario are that the stands will not contribute to mid-term timber supply and that structural and species diversity will be reduced.

Results Attack rates were higher than anticipated and originally assumed by timber supply analysts, with attack rates in immature stands (except age class 1) ranging from 40 to 60% and exceeding 80% in mature stands. Almost all pine were killed in mature stands. The percentage of trees attacked by the beetle, when considering all species, was significantly lower in older than in immature (pure pine) stands, because mature stands have more species, primarily sub-alpine fir, aspen and spruce. Generally, non-pine species were not attacked, except black and interior spruce, but the attack rate is < 1% for both species. The increase in non-pine species with age class is consistent with the shift in BEC subzones and variants. Site index did not correlate to the current incidence of mountain pine beetle. For some stands, the mortality and loss of attacked pines would promote more light in the stand structure allowing the other species to release and develop. If left alone, these stands could contribute to the medium- and long-terrn wood supply. Authors predicted attack for various age classes, DBH, by BEC zone. Age class 1 to 3 stands have significant amounts of advanced and seedling regeneration.

At the plot level, 85, 76, and 75% of TSPs age classes 1, 2, and 3 (respectively) have greater than 600 sph of advanced and seedling regeneration. Only 4.8, 8.5, and 10.6% of TSPs (age classes 1, 2, and 3 respectively) have no regeneration. At the plot level, 67, 72, 77, 74, and 77% of age class 4 to 8 TSPs (respectively) have greater than 600 sph of advanced regeneration. In age classes 4 through 8, 12.9, 15.9, 13.2, 9.8, and 9.0% of TSPs (respectively) have no regeneration. At the landscape level, mature forests had more TSPs with no regeneration than immature age classes. The younger age classes (1 through 3) appear to be dominated by advanced regeneration and residual mature trees, whereas regeneration in the older age classes (5 through 8) appears to be largely seedlings. Age class 4 appears to be transitional between the two. The greater amount of residual trees in the younger age classes is likely due to the lower beetle attack rates.

Gain in Knowledge The modelling scenarios indicate that exploiting secondary stand structure may be the best option for designing cost-effective and environmentally sound restoration strategies. Despite having considerable secondary structure at the landscape level, the release of secondary structure and competing shrubs in these stands must be quantified. An accurate inventory of post-beetle stand attributes is needed to determine which stands could benefit from restoration activities.

When using SORTIE-ND they had a high level of confidence in the modelled release of the mature tree layer; they were less sure of the modelled release of secondary structure and competing shrub layer. Actual release of secondary structure in beetle-attacked stands, both immature and mature, needs to be quantified in order to accurately project post-attack stand growth in SORTIE-ND.

Sattler, D.F.; LeMay, V.; Marshall, P. 2009. Estimating natural regeneration in stands following attack by mountain pine beetle using a linked-model approach. Pages 69–77 *in* D.P. Dykstra and R.A. Monserud, tech. eds. Forest growth and timber quality: Crown models and simulation methods for sustainable forest management: Proceedings of an International Conference, August 7–10, 2007, Portland, OR. USDA, Forest Service, Pacific Northwest Research Station, Portland, OR. USDA Forest Service General Technical Report PNW GTR 791.

Purpose/Study Area This project appears to be a precursor to Sattler et al. (2008) following. A linked-modelling approach, using PrognosisBC and SORTIE-ND, was tested for predicting natural regeneration and forecasting future stand conditions in beetle-attacked stands using data collected from the IDF, SBPS, SBS and MS biogeoclimatic zones of central and southeastern British Columbia. Potential stands for sampling were selected from an area which had been attacked by the beetle between the late 1970s and the late 1990s within approximately 200 km of Williams Lake, BC.

Methods Obtaining regeneration estimates from the light mediated growth model SORTIE-ND was identified as a possible alternative to the "Most Similar Neighbor" regeneration imputation techniques used by Prognosis. A method to link estimated tree lists for trees less than 7.5 cm DBH from SORTIE-ND to PrognosisBC was developed. Using a 25-year projection period, the timing of the tree list hand-off from SORTIE-ND to Prognosis was tested at 5 and 10 years post-attack and compared to simulations using Prognosis only and SORTIE-ND only for the entire projection period.

Results Although use of the linked-model approach provided slight improvements over using PrognosisBC only or SORTIE-ND only, overall results were generally poor. In particular, densities of lodgepole pine were largely underestimated for smaller trees.

Gain in Knowledge Further testing using an extensive dataset and further parameterization of the SORTIE-ND model is likely required if improvements are to be attained.

See also:

> LeMay, V.M.; Lee, T.; Scott, R.E.; Sattler, D.F.; Robinson, D.; Zumrawi, A-A.; Marshall, P. 2006. Modelling natural regeneration following mountain pine beetle attacks in the Southern and Central Interior of British Columbia: Results for Year 1. Internal Report for Natural Resources Canada, MPB Standard Contribution Agreement, PO # 8.35.

Sattler, D.; LeMay, V.; Marshall, P. 2008. Estimating natural regeneration and yield in pine-dominated stands following mountain pine beetle attack using SORTIE-ND and PrognosisBC in a hybrid modelling approach. FIA–FSP Project Y081048, Executive Summary.

Purpose/Study Area To develop a dynamic method for estimating the growth and yield unsalvaged, unmanaged beetle-attacked pine-dominated stands (***Pinus contorta*** var. ***contorta***). The research focused on attacked stands in the Central Interior (Quesnel/Williams Lake) and Southern Interior (Kamloops, BC) areas of the province. The specific objectives were:

- To examine the strengths of SORTIE-ND and PrognosisBC in estimating the establishment and growth of beetle-affected stands;
- To examine the factors affecting natural regeneration following beetle attack across a range of site and stand conditions using existing datasets;
- To alter parameters and sub-models of SORTIE-ND and PrognosisBC based on findings from the previous objective; and
- To link SORTIE-ND and PrognosisBC and estimate the growth and yield of trees following beetle-attack.

Method: The project began April 1, 2007 and will continue for two years ending March 31, 2009, with a final report and deliverables by April 30, 2009. Two sources of plot data were used in this project: UBC and NRC. The UBC dataset includes samples from IDF, SBS, SBPS, and MS BEC zones; the NRC dataset include measures of overstorey and understorey trees in the IDF, SBPS and MS

BEC zones for 41 stands. These data have overstorey measures in 1987 and 2001, and regeneration measures in 2001.

Results Interim conclusions/progress are presented for all objectives and are lengthy. More complete results will be available in the final report.

Gain in Knowledge The relatively rapid pace of change in forest structure following beetle attack has placed considerable importance on the need to develop dynamic quantitative growth and yield models, commonly referred to as hybrid models. Within a hybrid model system, estimates of future tree growth and stand conditions are obtained through a feedback system between empirically based predictions and processed-based predictions; the latter model the basic building blocks related to tree growth. This project attempts to improve the models or provide data for models.

Simard, S. 2009. Predicting development and productivity of southern interior mixed species stands following mountain pine beetle attack. FIA–FSP Project M086020, Final Technical Report.

Purpose/Study Area MS zone of the Southern Interior Forest Region.

Methods Simard's team completed an initial parameterization of the SORTIE-ND stand dynamics model for mixed stands in the Montane Spruce zone of southern interior British Columbia. They have quantified, for an initial subsample, the growth response of juvenile trees (< 10 cm DBH) growing under a range of light environments; characterized the probability of juvenile tree mortality; and investigated the effects of competition on the growth and survival of adult trees (> 10cm DBH). The study focused sampling on interior spruce, subalpine fir, and lodgepole pine. They then used this data to parameterize SORTIE-ND for southern interior MS mixtures, using northern interior data to fill gaps in southern interior data.

To examine the growth response of each test species to a variety of light conditions, they used the methodology described by Wright et al. (1998, 2000). Saplings (< 10 cm DBH) were destructively sampled across a light gradient and stem disks were collected. The radial growth of approximately 60 trees, growing under different light conditions, was measured in order to develop a light response curve. To characterize the probability of juvenile (< 10 cm DBH) mortality as a function of recent growth, they sampled live and dead saplings across a heterogeneous light environment. As described in Kobe and Coates (1997), stem cross sections from approximately 40 living and 40 recently dead birch trees were collected from each site and assessed for growth to develop a relationship.

Results Results are interim: all field sampling was completed; SORTIE-ND was re-parameterized using the field data; results of model runs were compared against long-term measurement data. Graphs of model runs and analyses were presented.

Gain in Knowledge Preliminary information on how stands will respond to beetle attack. Funding was expected to continue (FIA–FSP #Y091095) to complete the lodgepole pine sampling and collect parameter information for Douglas-fir and trembling aspen.

Kobe, R.K.; Coates, K.D. 1997. Models of sapling mortality as a function of growth to characterize interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. Canadian Journal of Forest Research 27:227–236

Wright, E.F.; Coates, K.D.; Canham, C.D.; Bartemucci, P. 1998. Species variability in growth response to light across a climatic gradient in northwestern British Columbia. Canadian Journal of Forest Research 28:871–886.

Wright, E.F.; Canham, C.D.; Coates, K.D. 2000. Effects of suppression and release on sapling growth for 11 tree species of northern, interior British Columbia. Canadian Journal of Forest Research 29:1775–1783.

8.1.2. Stand Structure Studies Documenting Habitats of Patches and Matrix

Brown, M.; Grant, N.J.; Black, T.A. 2008. The effects of salvage logging on the net ecosystem productivity of MPB-attacked lodgepole pine forest ecosystems of the northern-BC Interior. FIA–FSP Project M085111, Final Technical Report.

Purpose/Study Area The study compares carbon balances in adjacent salvage-logged and not-logged lodgepole pine stands of the Lakes, Quesnel and Prince George TSAs. Effects of salvage following beetle attack and salvage following fires are examined in terms of net ecosystem carbon exchange, photosynthesis and growth of understorey and/or planted seedlings, and soil and root respiration.

Methods They measured Net Ecosystem Productivity (carbon flux, photosynthesis, respiration).

Results Salvage harvesting after beetle can make the stand into a large carbon source two years following harvesting. This was expected given that little vegetation remained following harvesting and that the planted seedlings were still juvenile. Even a stand harvested 10 years ago left to regenerate naturally was still a moderate carbon source during the growing season despite an abundance of lodgepole pine saplings. In salvaged stands examined, respiration dominated over photosynthesis.

Unharvested stands were a carbon sink. In unharvested stands, the canopy accounted for ~ 75% of the total daytime ecosystem carbon uptake, with the understorey accounting for the remaining uptake, showing that despite most of the trees in the stand being dead, the remaining healthy trees and forest floor vegetation actively absorbed carbon.

Gain in Knowledge Clearcut salvage harvesting can turn a site into a carbon source for at least 10 years. Thus, the increase in the AAC will likely significantly reduce the ability of BC's forests to sequester carbon.

Chan-McLeod, A. 2007. Integrating silvicultural control of mountain pine beetle with wildlife and sustainable forest management objectives. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2007-05. (see also section 8.3.1)

Purpose/Study Area Chan-McLeod estimated differences in forest elements that provide wildlife habitat, windthrow, and tree mortality between harvesting treatments in beetle-attacked areas near Prince George in the SBSdw2 and SBSdw3, and SBSmw zones. The areas were mainly lodgepole pine and Douglas-fir with minor components of aspen, subalpine fir, and hybrid spruce.

Methods Treatments included:

- bark beetle recovery areas (< 15 ha with less than 12% retention),
- very large blocks (> 200 ha) with about 15% retention,
- partial harvest that retained 20% in groups,
- partial harvest that retained 20% in dispersed,
- partial harvest that retained 10% in groups,
- partial harvest that retained 10% in dispersed,
- beetle-infested, old-growth controls, and
- clearcuts.

They measured standing live and dead conifers, deciduous, downed conifer and deciduous (conifers and deciduous trees that were standing after harvest but came down afterwards), canopy close, CWD after harvest, shrub cover, and avian response. Because sample designs differed, plots for stand structure were not consistently the same as for avian response or windthrow, but all were in the same treatments. Some treatments were used for particular studies.

Results Dispersed retention kept larger basal areas; aggregated retention targeted more non-pine species than was present in controls; there was higher density of trees in aggregates than in dispersed retention treatments. Canopy cover was similar between controls and retained aggregates, but shrub cover was higher in aggregates. There was more grass in areas with lower canopy closure and more disturbance. Dispersed retention had more windthrow in all size classes than aggregated retention, but windthrow levels were quite high in all treatments (aggregates actually contained no trees of the largest size class). Douglas-fir veteran trees had lowest rates of windthrow, white spruce had the highest and should only be kept in aggregates.

Gain in Knowledge Effects of treatments on stand structure seem to relate to differences in exposure of treed units to light and wind caused by the removal of canopy. Dispersed retention treatments have high light and high wind and thus high windthrow, high grass cover, and low beetle kill after treatment. Treatment units with aggregated retention had lower light and lower wind exposure, leading to more shrubs, less grass, slightly lower windthrow, and moderate post-treatment mortality due to the beetle compared to dispersed retention treatments. Control areas (beetle-killed old growth) had lowest exposure to light and wind and thus had the lowest windthrow and low shrub and grass cover, but had high post-treatment mortality of trees due to the beetle.

Dubé, S.; Chapman, B.; Berch, S. 2006. Monitoring soil disturbance on harvested areas within the mountain pine beetle infestation. FIA–FSP Project M065005.

Purpose/Study Area Authors examined remotely sensed images with respect to: 1) description and 2) accuracy assessment of indicators of soil conservation in association with harvesting activities within beetle-affected areas. In the north and east, they evaluated images of recent beetle-attacked cutblocks from the Vanderhoof, Mackenzie, Rocky Mountain, and Prince George Forest Districts, and in central BC, they collected images of salvage logging from the 100 Mile House, Central Cariboo, and

Chilcotin Forest Districts. They chose those areas because different remotely sensed images were available, beetle-killed stands were abundant, and some field data obtained using the ground-based method existed to confirm the photo interpretation.

Methods They determined soil disturbance levels on five salvage-harvested blocks using a detailed ground-based soil disturbance assessment method (Soil conservation surveys guidebook, "10 hectare and smaller" method, BCMoF). In the northern and eastern Districts, they carried out the image-based soil disturbance method developed for the Forest and Range Evaluation Program (FREP) (based on 6 key indicators). Indicators were assessed across a range of digital image formats including satellite imagery and low-altitude aerial photography.

Results Access structures, particularly roads, and green tree retention in patches are evident on all remotely sensed images, but easier to capture on aerial photographs. Exposed soils in landings and roads yield a brighter spot than surrounding areas on black and white SPOT satellite images. Small areas (< 0.2 ha) where soil has been disturbed, such as landings, often appeared fuzzy and blended in with other ground features on low-resolution images with pixel size greater than 2.5 m. Surface wetness from drainage diversion displays as a darker colour and unfortunately often blends in with natural regrowth and brush, making interpretation difficult.

Gain in Knowledge The beetle assessment imagery is of the standard MoF quality, approximately 1:16 000. The resolution of this imagery shows the more obvious types of soil disturbance quite clearly while the more subtle kinds of disturbance, like compacted areas and some types of ruts, are much less obvious. Information needs should guide the choice of an appropriate data source for monitoring soil conservation following salvage operations within beetle-affected areas. Low-resolution data with spatial resolution of 15 to 30 m (e.g., Landsat TM) would be sufficient for detecting and measuring the extent of roads and landings. Finer images will provide higher accuracy measurements if necessary. Areas with landslides, erosion, drainage diversion, inordinate disturbance, or roadside work areas can be captured on remotely sensed images with spatial resolution greater than 2.5 m, such as SPOT, and 1-m pixel size image, such as Terrain Resource Inventory Mapping (TRIM). However, based on this review and previous work, aerial photographs are best suited to describe and accurately assess the less evident harvesting-related soil disturbance.

Dykstra, P.R.; Braumandl, T.F. 2006. Historic influence of the mountain pine beetle on stand dynamics in Canada's Rocky Mountain parks. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2006-15.

Purpose/Study Area Dykstra and Braumandl studied stand conditions following two mountain pine beetle outbreaks events in the 1940s and 1980s (65 and 25 years before present). Two lodgepole pine vegetation communities were sampled: Kootenay, Banff, Yoho—C6, C11, C38, mesic on various aspects in montane and lower subalpine zones; and Waterton—C65, C67, and C79; mesic on various aspects in montane and lower subalpine zones. Note that ecosystems (e.g., C6, C11, C38) are those described by Parks, and not typical BEC classification. They addressed the following questions:

- What is the post-beetle ecological character of stands?
- What ecological legacies should be sought post-beetle?
- Can or should ecological integrity be maintained in beetle-damaged landscapes?
- What are the beetle impacts on regeneration?

Methods They measured overstorey and understorey structural attributes, gathered cross-sectional tree discs and cores from the boles of regeneration, and surveyed vegetation communities in 85 randomly located stands. They then performed multivariate ordination on the overstorey and understorey structural attributes and the vegetation data to describe the relationships in the data set, and used analysis of variance on all data to examine treatment effects. They include a useful literature review on regeneration and growth release after beetle, tree fall, and snag creation.

Results

- Coarse woody debris (CWD), vegetation, and basal area varied most between treatments, but their order of contribution to the variation in the data differed between the two ecosystems. Beetle increased CWD 3.5 times over controls in some areas.
- The mountain pine beetle is an important contributor to snag densities, with a consequent effect on organisms that use dead and dying lodgepole pine trees. However, the pulse of snags and the associated forage and nesting opportunities is ephemeral; the beetle adds to the detritus cycle in several pulses: soon after attack when needles fall; within 10 years, as bark sloughs off; and within 15 years, when most dead trees have fallen. The similarities between the control and disturbed

stands in snag basal area 25 years following the disturbance in both ecosystems, and the differences between treatments in CWD suggest that most, if not all, of the beetle-induced mortality had passed through the snag stage to the CWD stage.

- The beetle stimulated understorey vegetation productivity—a sustained redistribution of resources between stands that persisted into the mid term.
- They observed release in many of the overstorey and understorey tree cores following the disturbance, but it was beyond the scope and resources of their study to quantify release. The significant differences in basal area between the disturbed and control stands show that a recovery period of 25 years following disturbance by the mountain pine beetle in Waterton Lakes and Kootenay, Banff, and Yoho, and of 65 years in Kootenay, Banff, and Yoho, is insufficient for stand basal area to approach the levels observed in the controls.
- They found either no notable pulse of regeneration or a delay in regeneration following disturbance.
- The beetle increased stand and landscape heterogeneity in three ways: via increased beta diversity of understorey vegetation, by creating stands in the advanced recovery stage that have different habitat elements than control stands, and by initiating various trajectories of ecological legacies in different ecosystems. The latter finding shows that different habitat values occur over time across the landscape, originating from beetle disturbances of similar timing.
- Ecological legacies existed and persisted following disturbance by the beetle, and recovery occurred gradually in disturbed stands, suggesting that an important "life-boating" function exists for these legacies. However, they found a different recovery response between ecosystems, which may indicate that resilience to the beetle and to any additional disturbance (e.g., salvage) differs between ecosystems.

Gain in Knowledge Some of the differences between findings in the two ecosystems suggest that rates of recruitment and persistence of ecological legacies vary between ecosystems, with consequent differences in the types of habitat values that ecosystems would provide at different times following a widespread disturbance. Therefore, management strategies should be adapted to local conditions. Because ecosystem recovery from beetle disturbance appears to vary by ecosystem, resilience to post-beetle management actions such as salvage logging will likely also vary between ecosystems; the type and intensity of rehabilitation should reflect the sensitivity of ecosystems to additional disturbance.

Hawkes, B.; Taylor, S.; Stockdale, C.; Shore, T. 2003. Impacts of mountain pine beetle attack on stand and ecosystem dynamics. FII Reference #R 2003-26.

Purpose/Study Area This report covers the second year of the study continuing the work of T. Shore (CFS–PFC) who investigated the effects of the 1980s mountain pine beetle epidemic on lodgepole pine forests. In early 2001, the study was revived to assess beetle impacts across a range of BEC zones and stand conditions, and to investigate modelling techniques for projecting post-epidemic stand and ecosystem development. Specific objectives included:

- Documenting effects of mountain pine beetle on stand structure/composition and regeneration.
- Documenting effects of the beetle on growth of residual stems.
- Documenting effects of the beetle on coarse woody debris dynamics (standing trees and fall-down rates).
- Documenting effects of the beetle on fuel loading, structure, and fire hazard.
- Re-evaluating Heath and Alfaro's (1990) study of Douglas-fir release at Bull Mountain.
- Establishing new plots to extend ecological range of knowledge.
- Investigating modelling techniques to project stand, ecosystem, and CWD dynamics, and fire potential.

Methods In 1987/88, study sites were established in 30, 6, and 5 stands respectively in the Cariboo, Kamloops, and Nelson Forest Regions. Due to subsequent logging and wildfire, only some stands were still available for resampling. New study sites have been established in stands in the current beetle outbreak in Tweedsmuir (10 sites) and Manning Provincial Parks (5 sites).

Results Empirical data were collected (and reported) on overstorey, understorey and CWD. Overstorey measures included diameter, species, and presence of fire scars and any pathogens. Standing dead trees were examined to determine the cause of death. Understorey measurements included tallies of seedlings by species and height class, and tallies of saplings taller than 1.5 m. Woody debris was examined on 30-m transects, and the diameter and species of each piece intersected by the transect tape were recorded. Each piece was assigned to one of five classes of decomposition. Fine fuels were tallied along the first 25 m of the transect.

Gain in Knowledge Empirical data are still needed on levels of mortality, growth of residual stands, fuel loading, and regeneration to effectively calibrate and test the models in a variety of beetle-affected stands. Preliminary results were used to determine the AAC currently being re-assessed for Williams Lake TSA, to prioritize and schedule the remaining salvage of stands affected by

the 1980s outbreak in the Cariboo Forest Region, and to salvage the current outbreak. Lignum Ltd. and Riverside forest company staff have used the preliminary results to assist in understanding the role of fire and MPB disturbances and their interaction, particularly how past disturbances have created current stand structures. These results have also assisted determining appropriate forest harvest and silvicultural systems that will approximate natural stand level processes and structure, while minimizing mountain pine beetle and fire losses.

Hawkes, B.; Taylor, S.; Stockdale C.; Shore, T.; Beukema, S.; Robinson, D. 2005. Predicting mountain pine beetle impacts on lodgepole pine stands and woody debris characteristics in a mixed severity fire regime using PrognosisBC and the Fire and Fuels Extension. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2005-22.

Purpose/Study Area Same as above (Hawkes et al. 2003 study, 1987–2001). They used PrognosisBC and Fire Fuels Extension (FFE) to project changes in stand structure fuel loading, snag density, and potential fire behaviours following mountain pine beetle outbreak on Chilcotin Plateau.

Methods The linked PrognosisBC–FFE model was used to project changes in stand structure, fuel loading, snag density, and potential fire behaviour for the 15 Chilcotin stands remeasured in 2001. As input, PrognosisBC uses a statistical inventory of live and dead trees in each stand. Tree lists were created for stand conditions in 1987 and 2001 by combining information about live trees, snags, saplings, and seedling regeneration. Regenerating seedlings were entered into the tree list using four height classes. Fuel loading estimates were available for most stands sampled in 2001 by stand and size used in FFE. A stand visualization system generated images of each stand to depict stand conditions.

Results Graphics display the 45 simulation runs made with PrognosisBC–FFE model and show changes in each stand over time, as measured by live trees, fuel, snags, and fire potential.

Gain in Knowledge The model has limited ability to empirically compare the 1987 inventory projected to the 2001 remeasurement. The discrepancy is amplified by sources of unmodelled mortality in many Chilcotin stands between 1987 and 2001, such as mountain pine and Ips beetles. The base PrognosisBC model does not capture this mortality, because these bark beetle outbreaks are not considered in the "background" mortality that was part of the model calibration. In stands with limited additional mortality, the model performed reasonably well for the live tree characteristics. The results indicate that the FFE snag dynamics should be revised to better represent the fuel and snag dynamics of the Chilcotin Plateau. CWD accumulations projected by FFE due to fallen standing dead trees are plausible judging by woody debris loads in 2001. The FFE model predictions indicate a need to increase the decay rate for fine fuels and decrease it for coarse fuels.

Klenner, W. 2009a. Developing retention strategies to maintain landscape-level wildlife habitat and biodiversity during the salvage harvesting of mountain pine beetle attack areas in the Southern Interior Forest Region. FIA–FSP Project M085266, Final Report.

Purpose/Study Area Applicable to Southern Interior of BC.

Methods The project provides a synthesis of the literature on multi-stand (landscape) effects of salvage harvesting in mountain pine beetle affected areas and identifies key principles that affect wildlife habitat and biodiversity at the landscape level. Assessed factors include:

- the amount of mature and late seral;
- patch size and shape of mature and late seral retention areas;
- the dispersion of key habitats;
- landscape-level connectivity;
- representation of ecosystem types in old and mature retention areas at the predictive ecosystem mapping level;
- the effects of roads and access;
- maintaining heterogeneity of treatments; and
- the role of within-stand structural conditions.

Review was complemented with discussions with operational staff and landscape-level habitat supply modelling using TELSA. The project continues work initiated in 2005–06 that focused on stand-level retention practices in beetle-killed salvage areas (see Klenner 2006).

Results The report notes five areas of concern for salvage:

1. The immediate and long-term loss of mature forest attributes, including large live trees, large declining or recently dead stems, and snags and downed wood of all sizes and decay conditions;
2. Connectivity and isolation effects, such as the loss of connectivity for dispersal by propagules or organisms with relatively poor mobility or that require hiding or thermal cover;
3. Reduced riparian habitat, or loss of the connectivity function of riparian areas through isolation effects;
4. Increased access for vehicle traffic and direct or indirect survival effects on carnivores and ungulates; and
5. Habitat homogenization. The report presents practical examples as well as diagrams and pictures of means of adding retention into beetle-attacked landscapes.

Gain in Knowledge Accelerated salvage to recover timber affected by the current beetle epidemic may impede non-timber objectives without appropriate retention practices. Case studies reveal that salvage logging can affect non-timber values through:

- elevated short-term risk of impaired ecological functions in salvaged than in unmanaged beetle-killed forests;
- increased long-term risk of impaired ecological function due to the potential for additional losses of structure through subsequent natural disturbances or logging; and
- increased vulnerability from human pressures previously managed through forestry activities.

Salvage harvesting is likely to further diminish stand legacies that remained following the beetle attack. Several issues impede retention: planning and implementing strategic land use objectives at the landscape or watershed scale is poorly co-ordinated, and there is a lack of incentives to implement structured and consistent retention planning and applications. Unless retention strategies are adequately developed and applied, undesirable effects on wildlife habitat attributable to salvage activities are likely.

> Klenner, W. 2006. Retention strategies to maintain habitat structure and wildlife diversity during the salvage harvesting of mountain pine beetle attack areas in the Southern Interior Forest Region. BC Ministry of Forests and Range, Kamloops, BC. Extension Note 04.

McHugh, A. 2009 Assessing the effectiveness of management strategies in creating and maintaining stand-level biodiversity on large-scale mountain pine beetle cutblocks in the Arrow Boundary Forest District. FIA–FSP Project M085166, Executive Summary.

Purpose/Study Area To assess the efficacy of using timber cruise information and pre- and post-harvest FREP data as baseline information in FREP (Forest and Range Evaluation Program) Stand Level Biodiversity assessments on beetle-killed salvage cutblocks in the Arrow Boundary Forest District.

Methods The project began in 2006. Using three data sources (timber cruise data, FREP pre-harvest data, and FREP post-harvest data), McHugh conducted pre- and post-harvest surveys and evaluated trends in indicators within and across seven cutblocks. Mean densities for live and standing dead trees by diameter class, total live and dead trees, functional snags, large trees, tree species composition, and qualitative indicators were analyzed.

Results Results indicate that the three methods substantially overlapped in assessing many stand structural characteristics. Large trees (live, dead, and live and dead combined) were evident in very small numbers in both the timber cruise and post-harvest FREP samples, but were not recorded in the pre-harvest FREP data. FREP data generally had fewer tree species identified than timber cruise data, with species absent from FREP data generally recorded as rare in the timber cruise. Lastly, some important stand structural attributes, such as CWD and wildlife tree classifications (i.e., ecological decay class) are not collected under the current timber cruise protocol.

Gain in Knowledge Rare forest elements may be misrepresented in both timber cruise and FREP samples, and some potentially valuable data are currently missing from timber cruise statistics.

Vyse, A. 2009. Sustainable management of the ponderosa pine parkland ecosystems in the Thompson River watershed after the mountain pine beetle epidemic. FIA–FSP Project Y081240, Executive Summary.

Purpose/Study Area The project will describe the short- and long-term ecological impact of mountain pine beetle on ponderosa pine stands and the disturbance history in these stands.

Methods The project (2008–10) will establish a system of permanent transects to assess variation in ponderosa pine ecosystem components, stand history, and beetle mortality. Transects to record bird species and invertebrate species (ants, grasshoppers,

and butterflies), and plots along transects to measure live and dead trees, regeneration, ground light levels, and soil and vegetation conditions. Plots will also be assessed for disturbance history, by collecting fire scars and tree cores, and for conifer seed production and fuel loading. First Nations ecological, biological, social, cultural, and economic interests in Ponderosa pine forest will be assessed.

Results None reported yet.

Gain in Knowledge None reported yet.

Waterhouse, M.; Newsome, T.; Arsenault, A. 2008. Shelterwood silvicultural systems to address integrated resource management issues. FIA–FSP Project Y081145, Executive Summary.

Purpose/Study Area These are silvicultural systems trials. The SBS trial, initiated in 1990 in the SBSdw BEC subzone in the Central Cariboo Forest District (Williams Lake), was designed to attain natural Douglas-fir regeneration through the use of uniform shelterwood silvicultural systems. The ICH trial in the Kootenays was initiated in 1993 because a significant percentage of the landbase was being harvested with partial retention systems to meet guidelines for visual, ungulate habitat, and other values.

Methods SBS, started in 1990; ICH, started in 1993. These projects have been funded as BC Ministry of Forests and Range Experimental Projects 1104.01 (SBS) and 1186 (ICH) through several funding agencies (BC Ministry of Forests Silvicultural Systems Project, FRDA II, FRBC, FII and FIA).

The trials include many silvicultural systems. A variety of measurements from overstorey, understorey, light, and organisms are included in the studies.

Results Several reports have been produced; these were not searched out and it is unknown if any are specific to the beetle. In the executive summary, authors mentioned a wind event had produced "high" fall rates of residual trees in a harvest treatment that retained low basal area uniformly over the block.

Gain in Knowledge The executive summary does not indicate conclusions; more reports need to be gathered to assess whether issues specific to mountain pine beetle were addressed.

Welham, C.; Seely, B. 2007 The implications of management practices for mitigating mountain pine beetle on ecosystem production and soil-based indicators of SFM. FIA–FSP Project Y071160.

Purpose/Study Area This project links field estimates of forest floor and soil organic matter (SOM) from Canfor's Quesnel Division, with simulated outcomes of the different options using the ecosystem model FORECAST.

Methods Measures of forest floor and SOM pools were obtained in August 2006 from beetle-killed lodgepole pine stands in the timber harvesting land base (THLB) that were slated for salvage logging. Soil texture and coarse fragment content (> 2 mm) were determined from standard soil procedures. Samples were analyzed in the laboratory for bulk density. Carbon and nitrogen content were derived.

The main objective of the modelling exercise was to simulate a set of stand-level strategies designed to mitigate susceptibility to the beetle and determine their effect upon SOM, carbon, forest floor mass, and the associated nitrogen content, measures that Canfor's Quesnel Division is monitoring as part of its Sustainable Forest Management (SFM) program. First, the FORECAST model was used to simulate the development of salvage-logged stands using their SOM content from the field study as a starting condition, in conjunction with various management options. The simulated stands were planted to varying proportions of pine and hybrid spruce (80% lodgepole pine + 20% interior spruce, 20% pine + 80% interior spruce), without and with fertilizer (the latter case, applied in years 20, 25, and 30 at a rate of 200 kg N/ha). An understorey shrub and grass community was included in all simulations. The starting site index for the simulations was derived from the field estimates. Thereafter, site index was permitted to vary so as to determine how management activities affect the inherent productivity of the site. FORECAST output then was linked to the Shore and Safranyik beetle susceptibility rating (SR) model and the latter used to calculate the change in stand susceptibility over time. The linked FORECAST-SR model was used to calculate potential rotation lengths for all of the species–planting–fertilizer combinations, according to each of three criteria:

1. minimal acceptable beetle susceptibility (the rotation length where the susceptibility index equals 20%),
2. culmination of mean annual increment (MAI), and
3. maximum expected net benefit (calculated from the susceptibility index times merchantable volume, at each year in the rotation).

Results

- Harvesting at the culmination of mean annual increment (MAI) consistently produced the highest merchantable volumes with no risk of soil degradation in site series with the lowest (the SBPSdc 03) or highest (the SBSmc02 01) soil organic matter content. Harvesting according to MAI also generally had the longest rotation lengths.
- If CANFOR were to implement subsequent harvesting practices on short rotation, then in pine-leading stands on nutrient-poor sites (the SBPSdc 03, for example), harvesting that maximizes expected net benefit (MENB; a criterion that accounts for both merchantable volume and stand susceptibility to mountain pine beetle) is the most feasible strategy. In unfertilized stands, this introduces a risk of soil organic matter degradation that can, however, can be mitigated with fertilizer. Fertilization has the added benefit of an increased merchantable volume and reduced rotation length.
- In spruce-leading stands on nutrient-poor sites, MENB generates the highest volumes but rotation lengths are too long for short rotation forestry. The Mountain Pine Beetle Strategy (MPBS, a criterion that accounts only for stand susceptibility) generates reasonable merchantable volume with no risk of SOM degradation and no need for fertilization.
- In pine-leading stands on nutrient-rich sites (the SBSmc2 01, for example), good merchantable volume production can be generated by harvesting according to MENB, but it risks long-term SOM degradation that is only partly mitigated by fertilization.
- In spruce-leading stands on nutrient-rich sites, MENB generates the highest volumes but rotation lengths are too long to be appropriate for short rotation forestry. Good merchantable volume production can be generated by harvesting according to MPBS but there may be a risk of long-term soil degradation.

Gain in Knowledge To ensure adherence to Indicator 2-1: (Biological components of forest soils are sustained) without the necessity for costly intervention (fertilization, for example), those site series within Canfor's THLB with lower SOM carbon content should be managed carefully to ensure that soil organic matter pools are not degraded unnecessarily.

8.1.3 Stand Structure Studies with Wildlife Focus

Aukema, B.H.; Klingenberg, M.D. 2007. Stand and forest dynamics following MPB: How spatial patterns of salvage harvesting affect Warren root collar weevil pressure in regenerating stands. FIA–FSP Project M075046, Executive Summary.

Purpose/Study Area To investigate how the spatial patterns of salvage logging will affect recruitment and success of both planted and naturally regenerating stands and how salvage might affect weevils. Salvage logging beetle-killed stands may decrease endemic resident weevil populations or the opposite may be true. This project provides an understanding of the spatial pattern of attack/mortality of Warren root collar weevil in regenerating stands adjacent to beetle-killed stands, and allows inferences of processes that may be driving such patterns. The study area is the Prince George, Nadina, Quesnel, and Vanderhoof Forest Districts (1 Apr 2006 to 31 March 2008).

Methods They selected 6 to 10 regenerating cutblocks aged 4 to 7 years post-stocking adjacent to beetle-killed stands. They attempted to select relatively flat, uniform sites. Slope, elevation, aspect, block:edge ratio, age, and stocking density were measured for each site. Their hypothesis posits that the habitat destruction caused by the beetle helps Warren root collar weevils move into new regenerating stands. In each stand, they established 100-m transects (not clear how many) stretching from the edge adjoining the beetle-killed stand toward the centre of the regenerating block. For all trees along the 8-m wide transect, they measured location, height, origin (planted/natural/unsure), condition (e.g., forest health problems such as stem rusts), and vitality (i.e., live or dead; dead trees will include those with yellow or red needles and lack of bud growth). Every 50 m they conduct a more intensive sampling of an 8-m portion of the transect for weevil injury (i.e., feeding scars and circumference girdled) on every tree. These intensive subplot samplings involved examining the root collar of each tree.

Results Graphical analysis has shown Warren root collar weevil has created a gradient of mortality in approximately 60% of stands examined in 2006. They are currently working to determine mechanisms that may be responsible for the patterns. Conclusions will follow year two of this project.

Gain in Knowledge Too early to assess.

Botting, R.; DeLong, C. 2008. Bryophyte and lichen communities on coarse woody debris in sub-boreal spruce forests. FIA–FSP Project M085007, Final Report.

Purpose/Study Area The study was conducted within the Prince George, Vanderhoof, and Fort St. James Forest Districts. Sample plots were located in the SBSdk, dw2, dw3, mc2, mc3, and mk1 BEC units. Objectives included:

- To characterize the environmental conditions and CWD characteristics that influence lichen and bryophyte diversity and abundance on CWD in contiguous forest stands.
- To examine the influence of patch size, time since isolation, and edge orientation of wildlife tree leave patches on their ability to maintain lichen and bryophyte communities.
- To study the influence of overstorey canopy tree species composition and proportion of dead pine trees on terrestrial lichen and bryophyte communities in mountain pine beetle affected forests.

Methods Two types of areas were sampled:

1. wildlife tree patches > 0.6 ha that had been isolated (i.e., logged around) over years ranging from the present to > 10 years ago; and
2. contiguous forest areas with varying proportions of pine in the canopy.

Wildlife tree patches were selected in which < 33% of the canopy was dead lodgepole pine (to reduce influence of dead pine) and which was not salvage logged. Patches ranged from 0.6 to 3 ha and had been logged between 2005 and prior to 1998. Lichen and bryophyte communities were assessed on CWD at the point of interception of the transect line.

Results The composition of lichen and bryophyte communities varied by decay class with the highest diversity of species living on intermediately decayed CWD. Height off the ground and CWD tree species also were important characteristics defining lichen and bryophyte communities. Logs above the ground supported lower abundance and fewer species.

Wildlife tree patches averaging 1.1 ha declined in liverwort and moss species diversity and cover over time since isolation. Liverworts in particular showed a steady decline. However, these patches had more CWD available and maintained some moss and lichen species that were at low cover or absent from the surrounding clearcut.

Patch size showed no influence (within the range studied, 0.8–3.3 ha) on abundance or diversity. Patch orientation influenced lichens and bryophytes differently with decay class: moss and liverwort cover and diversity were higher on north-facing edges for decay classes 1–3 and south-facing edges for class 4.

In 2007, plots were completed in stands with > 66, 33–66, and < 33% grey–dead lodgepole pine canopy and in 2006 plots were completed in stands with pine-dominated canopy (> 66%) which was largely red dead pine. Species richness of liverwort, lichen and moss among these four stand types declined with increasing proportion of pine in the canopy. A comparison of the two stand types with > 66% pine but with differing stages of tree death indicated that the influence of pine death is less clear.

The total number of species found on decay class 2 pine CWD logs was low for all forest types. Insufficient replication of pine CWD was available in decay classes 3 and 4 to allow for comparisons.

Gain in Knowledge This study highlights the importance of variety in CWD substrates (species and decay state) to maintaining diverse lichen and bryophyte species. Differences in lichen and bryophyte communities between species of CWD speak to the importance of mixed stands in contributing CWD. In their current size and configuration, wildlife tree patches do not seem to conserve liverwort and sensitive moss species. They may be able to conserve less susceptible species of mosses and lichens but may not be sufficient for sensitive species. Retention of larger patches (> 4 ha) is likely required to preserve the more sensitive liverwort species. This estimate appears to have been revised in a recent manuscript (in prep.) which suggests > 2 ha (Delong, BCMoFR, pers. comm. 2010). The edge aspect of wildlife tree patches should also be considered in wildlife tree patch configuration as the increased light penetration on south-facing edges may further affect liverworts and mosses.

Chan-McLeod, A.; Zhu, X.; Klinkenberg, B. 2008. Factors affecting the ecological legacy of unsalvaged post-mountain pine beetle stands. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-19. (see annotation in section 8.3.1)

Cichowski, D. 2007. Mountain pine beetle/lichen project Quesnel TSA. FIA–FSP Project Y071328. Year 2 Report.

Purpose/Study Area This project established permanent sampling sites in the "modified harvest" portion of the Itcha–Ilgachuz caribou winter range in the Quesnel TSA to monitor changes in terrestrial forage lichen abundance in response to the current beetle epidemic. The very dry, very cold subzone of the Montane Spruce (MSxv) biogeoclimatic zone covers most of the study area with the moist, cool subzone of the Sub-Boreal Pine Spruce (SBPSmk) at lower elevations.

Methods In Year 1 (2005–06), Sites 1 to 6 were established, as was a portion of Site 7. In Year 2 (2006–07), Sites 8 to 10 were added and Site 7 completed. Each plot established in 2005–06 was revisited to re-photograph the plot, remeasure vegetation

cover, update tree status, and take a hemispherical canopy photo. Data summarized are from years 1 and 2 combined. Data were collected on beetle attack, soil characteristics, humus, downwood, moisture regime, vegetation cover, conifer regeneration, cones, windthrow, light availability, and cover of lichen/moss, kinnickinick, twinflower, and arboreal lichens.

Results Interim only.

Gain in Knowledge Although terrestrial lichens grow very slowly and any potential increase in terrestrial lichen abundance may take many years, vegetation that competes with terrestrial lichens can respond quickly, resulting in a rapid decline in terrestrial lichen abundance. Research conducted on the response of terrestrial lichens to the beetle in the East Ootsa and Entiako areas, northwest of the Quesnel TSA, documented a decline in terrestrial lichen abundance with a corresponding increase in competing vegetation, primarily kinnikinnick, on many study plots from 2001 to 2005 (Williston et al. 2006). Other competitors that increased with a corresponding decrease in terrestrial lichen abundance include red-stemmed feathermoss and twinflower, but these competitors had less impact overall than kinnikinnick. Although the 10 sites in the Quesnel TSA study area are located in a different BEC subzone (MSxv) than the subzones in the East Ootsa/Entiako study (SBSmc2, SBSdk, SBPSmc, ESSFmc), if response of competing vegetation on sites in this study area is similar to that in the East Ootsa/Entiako area, a response in terrestrial lichen abundance could occur in as little as 2 years. Some sites are beginning to change. The author recommended remeasuring plots in 2008.

Williston, P.; Cichowski, D.; Haeussler, S. 2006. The response of caribou terrestrial forage lichens to forest harvesting and mountain pine beetles in the East Ootsa and Entiako areas: Final Report 2005, Years 1 to 5. A report to Morice Lakes Innovative Forest Practices Agreement, Prince George, BC; the Bulkley Valley Centre for Natural Resources Research and management, Smithers, BC; and BC Parks, Smithers, BC.

Lewis, D. 2008. Quantitative synthesis of wildlife habitat relationships to stand-level green tree retention following harvest and natural disturbance in lodgepole-pine dominated (NDT3) habitats. FIA–FSP Project S084014, Executive Summary.

Purpose/Study Area This project synthesized results from existing literature to evaluate the form of the relationship between wildlife abundance and residual forest structure following natural disturbance or forest harvesting and, if possible, identify threshold levels in loss of habitat structure. Synthesis focused on five common arboreal and forest floor small mammals: three species commonly associated with mature forest condition: northern flying squirrel *(Glaucomys sabrinus)*, red squirrel *(Tamiascuris hudsonicus)*, and southern red-backed voles *(Clethrionomys gapperi)*; and two species associated with more diverse habitat types: yellow-pine chipmunk *(Tamius amoenus)* and deer mouse *(Peromyscus maniculatus)*.

Methods To complete the analysis they took the ratio of small mammal abundance in a partially harvested stand to an uncut or pre-treatment stand and compared it to the relative difference in forest structure between a treated stand and an uncut control. Relative average abundances of small mammals, weighted by the number of years of sampling and treatment replicates, for each treatment type in each study were used as a single data point. A smoothing spline curve and confidence intervals were fit to the data for all studies to examine the form of the relationship between relative species abundance and relative basal area.

Results Synthesis of existing studies showed a near-linear decline in flying squirrel and red-backed voles with declining relative basal area; the decline in red squirrels was less clear. Chipmunk and deer mice showed a positive response to mature forest canopy loss. Flying squirrel declined linearly with lower residual basal area in recent (< 10 years) partial tree removal treatments, but the shape of this curve was strongly influenced by a single study reporting results from treatments with little retention (< 30%). Red-backed voles declined dramatically with lower relative basal area, although the rate of decline appeared to diminish below 40% relative basal area, suggesting red-backed vole may persist in stands with low relative basal area. Results from studies with recent higher levels of tree removals showed a markedly greater abundance of chipmunk, consistent with reported reduction in forage competition as red squirrel abundance declined in these same treatments. The shape of the curves for flying squirrel, red squirrel, and red-backed voles were strongly influenced by studies completed within regenerating forests following clearcut harvest or regenerating forest with some residual forest overstorey (< 30 years old). These regenerating stands had relatively high densities of forest-dependent small mammals comparable to uncut forest controls. Results suggest relatively rapid recovery of forest-dependent small mammals in regenerating stands, and that residual stand structure will influence abundance and persistence in both unsalvaged and salvaged beetle-affected forests.

Gain in Knowledge In beetle-affected forests left unsalvaged, they expect the decline in abundance of forest-dependent small mammals will be lower compared to salvage logged stands, while species such as chipmunk and deer mice should thrive under both conditions.

McNay, S. 2009. Identifying factors affecting the succession of terrestrial lichen communities in the Omineca Region of north-central British Columbia. FIA–FSP Project Y091186.

Purpose/Study Area To undertake research that synthesizes several aspects of ungulate winter range (UWR) ecology to build new understanding of relationships among site factors, terrestrial lichen abundance, beetle-killed timber and snowpack development. With this new knowledge, a second phase of research will be focused on the relationships between fire and lichens to test management for regenerating terrestrial forage lichens.

Methods They expect the assessment of these data to reveal relationships between snowpack and lichen abundance and believe correlation of these factors is tied to the transitional use by caribou pending tradeoffs between them. They propose ungulate winter ranges (UWRs) could be managed more effectively if this tradeoff were better understood and delineated geographically. Some data are already available from previous work (i.e., pre-infestation) and can be incorporated with new data to evaluate and contrast UWR conditions pre- and post-beetle attack.

In the absence of industrial activities, and in partnership with BC Parks, they propose adaptive management using small-scale treatments of prescribed fire to determine the feasibility of restoring lichen microsite conditions where necessary to do so.

Results None yet.

Gain in Knowledge None yet.

Munro, R.; McLellan, B.; Apps, C. 2008. Implications of forest management in response to the 1970's mountain pine beetle infestations on grizzly bears and moose in the Flathead Drainage. FIA–FSP M086037.

Purpose/Study Area The study is retrospective. The authors state that much can be learned about effects of mountain pine beetle on grizzly bear from an old outbreak in the Flathead.

Methods Radiotracking to determine seral stage use.

Results This paper has several chapters (see section 8.4); the chapter by Munro has information relative to stand structure. He found that on average, female grizzly bears in 2005 spent 30% of their time in either pine-dominated stands or regenerating cutblocks. Regenerating cutblocks and young second growth stands were among the least favoured habitats because of the lack of food. Grizzly bears are likely using these habitat types for purposes other than vegetative feeding. Mature forests are often areas used for bedding, while bears have been known to forage for ants in regenerating blocks. Grizzly bears are opportunistic predators and may be moving through these areas in search of ungulates. Because they were unable to visit any sites immediately after the bears had been there, they were unable to determine the type of activity the bear was engaged in at the time of use. If bears were using any of these habitat types for anting they would expect to find a correlation between the quantity of dead wood present and treatment type. Snag density within regenerating cutblocks was significantly higher at grizzly bear use sites suggesting that bears may be anting in cutblocks.

Gain in Knowledge This chapter adds superficially to knowledge of beetle impacts—maybe ants will increase after beetle and benefit bears, but Flathead bears have not been recorded as eating ants.

Nealis, V. 2007. Balancing disturbances in forest management. FIA–FSP Project M075045.

Purpose/Study Area To examine the effect of stand-level modifications resulting from removal of lodgepole pine to mitigate losses from the beetle on the risk of disturbance to residual Douglas-fir from the western spruce budworm. The first year of the project established plots over the southern interior, from Cache Creek, throughout the Nicola Valley and south to the Kentucky–Allyne region north of Princeton. Steps to extend to the southern Cariboo and north to Knife Creek (Williams Lake) in 2007–08 are underway so the study will cover the major range of Douglas-fir and lodgepole pine currently affected by western spruce budworm.

Methods Project runs from April 2006 to 31 March 2008. Linked (previous FSP) to Noseworthy project below.

Results Results to date indicate removal of lodgepole pine from mixed stands did not increase risk of damage from western spruce budworm. Their detailed study, however, hopes to show that the change in forest structure resulting from the silvicultural intervention alters some of the stage-specific survival patterns of budworms in systematic ways. That won't be known until the second year is analyzed.

Gain in Knowledge Suggestion that budworm impacts may be increased by certain silvicultural practices in response to mountain pine beetle, but no details available yet.

Noseworthy, M. 2008. How does forest structure affect western spruce budworm populations? FIA–FSP Project M086045.

Purpose/Study Area Focused on higher elevation mixed lodgepole pine and Douglas-fir stands. While the removal of lodgepole pine trees may reduce stand susceptibility to the beetle, the resultant forest may be vulnerable to other major forest pests, such as the western spruce budworm. The objective of M086045 was to examine changes in the population ecology of spruce budworm resulting from these changes in forest structure.

Methods Literature review.

Results Literature provides considerable evidence that the population ecology of western spruce budworm is influenced by stand structure of preferred hosts.

Gain in Knowledge Circumstantial evidence suggests that differences in observed damage between stands correlate to differences in their respective stand structure, but few direct and replicated manipulations of stand structure have quantified these relationships. No studies have concurrently observed the processes associated with structural changes and other pests.

Sullivan, T. 2008. Stand structure and maintenance of biodiversity in green tree retention stands at 30 years after harvest: A vision into the future. FIA–FSP Project Y083008, Executive Summary.

Purpose/Study Area Bald Range 25 km west of Summerland, BC, in the MS zone, in 30-year-old stands of lodgepole pine, with a range of green tree retention (dispersed and aggregated Douglas-fir), and uncut mature/old-growth stands. The study compares:

- Stand structure attributes (species diversity and structural diversity of herb, shrub, and tree layers);
- Population dynamics of two species (masked shrew and red-backed vole) of forest-floor small mammals and overall species richness and diversity;
- Population dynamics of two species (red squirrel and northern flying squirrel) of arboreal small mammals: the northern flying squirrel and red squirrel; and
- Relative habitat use by mule deer during summer and winter seasons.

Methods 2005–08. Does not say how stand structure measurements were collected. Experimental design was completely randomized with three replicates each of:

- young pine (no residual trees)
- single seed tree (dispersed retention)
- group seed tree (aggregated retention)
- uncut stands.

Forest floor small mammal species were sampled at 4-week intervals from May to October each year.

Results Mean total abundance of forest-floor small mammals was similar among stands, but some species show different preferences. Stands had no overall difference in mean total species richness.

Gain in Knowledge We found no technical reports, just a third-year executive summary. No stand structure information in this executive summary, but clearly the stand structure information was collected.

Waterhouse, M. 2008. Silvicultural systems to maintain northern caribou habitat in lodgepole pine forests in central BC. FIA–FSP Project Y081133, Executive Summary.

Purpose/Study Area The study blocks (in Itcha–Ilgachuz) occur in the Very Dry, Very Cold Montane Spruce (MSxv) and very dry, cold Sub-Boreal Pine–Spruce (SBPSxc) BEC subzones and range in elevation from 1260 to 1640 m. Lodgepole pine is the dominant tree species.

This project developed and tested silvicultural systems that maintain caribou habitat, specifically terrestrial and arboreal forage lichens, while extracting timber. Other parts of the research trial have focused on regeneration (planting and natural ingress), commercial mushrooms, breeding birds, microclimate, and long-term site productivity.

Methods Project started in 1995 (long-term research installation, BC Ministry of Forests and Range Experimental Project EP1208 funded previously by the BC Ministry of Forests Silvicultural Systems program, FRBC, and FII.). The trial was designed as a randomized block experiment with five replicate blocks of 60 to 80 ha. Each block was split into four units and randomly assigned four treatments including no-harvest. There are two irregular group shelterwood (IGS) systems where 50% of the stand area is cut every 70 years in openings ranging in diameter from 20 to 30 m, one whole tree and one stem-only harvest; also two group selection (whole tree and stem-only harvest) based on one-third area removal every 80 years and openings of 15 m in diameter. This system was developed for sites with abundant arboreal lichen (about 15% of the winter range). It was stem-only harvested. The blocks were harvested in 1996. Four of the blocks were paired with clearcuts that were whole-tree harvested.

Results In the second assessment period (2001–07) the annual fall rate for dead and live combined was 1.7 to 3.8% per ha per year and was not significantly different in the harvesting treatments. Results from the first assessment period are reported in MFR Extension Note 70.

Breeding birds were surveyed 1 year pre-harvest (1995) and 4 years post-harvest (1996–2001) to measure the response to partial cutting in old lodgepole pine forests on the Chilcotin Plateau of British Columbia. The irregular group shelterwood and group selection systems recommended to manage northern caribou ***(Rangifer tarandus caribou)*** habitat did not negatively affect the breeding bird community. In some years within the post-harvest period, dark-eyed juncos, red crossbills, yellow-rumped warblers, and gray jays showed significant ($\alpha = 0.05$) increases in use of the partial-cutting treatments compared to the no-harvest treatment. No species decreased significantly in any of the partial cutting treatments. The increased observations of mostly common species resulted in significantly ($\alpha = 0.05$) higher species richness, and increased frequency of observations for the bird community in some years in the partial cuts. Partial cutting of caribou habitat will maintain bird communities typical of mature to older lodgepole pine forests. An article was published in the *BC Journal of Ecosystems and Management*, July 2007.

Common terrestrial lichens and mosses were measured pre-harvest (1995) and at 2- to 4-year intervals post-harvest (1998, 2000, and 2004) to monitor the response to partial cutting. The initial loss of forage lichens approximately equaled the percent of area harvested, with greater loss in the openings than in the residual forest. After 8 years, forage lichen in the group selection treatment recovered to pre-harvest amounts, while lichen in the shelterwood treatments steadily increased from 1998 to 2004.

Pine mushrooms, shingled hedgehog, sheep polypore, black morels, and truffles have been sampled over several post treatment years. Partial cutting positively benefits some species. The first 8-year-results of soil temperature studies are published in MOFR TR021 and summaries are completed for the last 3 years. Measures of light transmission began in 2007.

Gain in Knowledge Information is provided on a number of resources including birds, lichens, mushrooms, and stand structure. Study results suggest that lodgepole pine and interior spruce can be successfully regenerated in irregular and group selection harvesting systems with optimal growth in gaps enlarged to 0.15 ha. Small openings in the SBPSxc can be naturally regenerated by lodgepole pine without post-logging site preparation but higher elevation blocks in the MSxv will need to be planted to ensure full stocking by lodgepole pine within 7 years. A journal article was published in *BC Journal of Ecosystems and Management* in July 2007. The fifth year results were published in Forestry Chronicle, and the tenth year data will be published in 2008–09.

Williston, P.; Cichowski, D. 2006. The response of caribou terrestrial forage lichens to forest harvesting and mountain pine beetles in the East Ootsa and Entiako areas. FIA–FSP Project Y061134, Final Report.

Purpose/Study Area To determine the response of caribou terrestrial forage lichens to forest harvesting and mountain pine beetles under various ecological conditions in four BEC subzones (SBSmc2, SBSdk, SBPSmc, and ESSFmc) in the East Ootsa and Entiako areas.

Methods Data presented represent localities that support high lichen cover within these site series or subzones and cannot be used to characterize average conditions within them.

The project began in 2001 and 2005 marks the fifth year of the study, which has documented changes over four growing seasons. In 2005, they collected additional stand structure and regeneration information at each plot to contribute to other studies lead by D. Coates, Ministry of Forests, and P. Burton, Canadian Forest Service (Forest Sciences Program Y061184, annotated above under entry for Burton and Brooks 2007, FSP Y072184). Data from this project has contributed to an assessment of secondary stand structure in lodgepole pine stands affected by the mountain pine beetle epidemic (Coates et al. 2006).

Results The study has documented amounts of canopy tree mortality and the associated changes in canopy cover. They did not directly measure needle deposition, changes to evapotranspiration levels, changes in canopy interception of precipitation,

or changes to the water table. They initially expected a response of the forest floor vegetation to take several years and to be difficult to detect, but dramatic changes were taking place within the first few seasons. In areas with heavy beetle attack, more than 50% of the canopy trees have died. This has had a number of effects on the ecosystem, including:

- a reduction of canopy tree evapotranspiration;
- a loss of precipitation interception by the canopy;
- a large deposition of needle litter over the forest floor;
- an increase in light availability at the forest floor; and
- an increase in the water table.

Canopy tree death resulted in a needle pulse 2 to 3 years after beetle attack. Lichens appeared to recover in 1 to 2 years. The quick response of lichens (compared to work in Finland) may reflect differences in the amount of needle litter; the BC study may have had less litter. Observations in the field suggest that kinnikinnick is not hampered by needle litter and often flourishes where needles accumulate. The response of red-stemmed feathermoss or crowberry to large depositions of needles is unknown.

While canopy openness and light availability have increased in response to the beetle attack, these canopy changes do not appear tied to the initial decrease in lichen cover. Lichens and understorey plants might take more than 5 years to respond to changes in light availability and respond in future years.

Gain in Knowledge Ecosystem responses to the beetle attack discussed above represent changes to growing conditions for terrestrial forage lichens and their competitors. Some of these responses, such as changes in light availability and living basal area, had relatively little influence on the cover of lichens, at least in first few years after the beetle attack. The needle pulse produced short-term changes that were negligible after 5 years. And yet, the cover of lichens has diminished, more so in some sites than in others. Authors suspect the reduction in lichen abundance is strongly linked to a landscape-level increase in the water table. They do not have the necessary hydrological data to confirm this speculation.

Youds, J. 2009. Effects of a mountain pine beetle epidemic on forest floor vegetation dynamics and lichen regeneration in the Itcha Ilgachuz caribou winter range in the Quesnel TSA. FIA–FSP Project Y091176, Project Description.

Purpose/Study Area This study was initiated in 2005 in the Quesnel TSA to examine effects of the beetle epidemic on understorey vegetation dynamics, terrestrial lichens, and regeneration.

Methods In 2005, seven permanent sample sites were established and the project was set up as an official BC Ministry of Forests and Range Experimental Project (EP# 1208.01). In 2006, three more permanent sample sites were established in the Quesnel TSA and upgraded canopy cover information was collected for all 10 sample sites. For this project, they propose to remeasure the 10 permanent sample sites in the Quesnel TSA following experimental design and methods used in the southwestern and central part of the Itcha Ilgachuz winter range. The design of this project is for remeasurement of the permanent sample sites every 3 years.

Results Just starting, so no results yet.

Gain in Knowledge Many studies are currently examining regeneration and advanced regeneration in a post-mountain pine beetle landscape; few focus on forest floor vegetation dynamics. The study could provide useful information.

8.1.4 Stand Structure Studies Focused on Risk of Beetle

Barclay, H.J.; Li, C.; Benson, L.; Taylor, S.; Shore, T. 2006. Effects of fire return rates on traversability of lodgepole pine forests for mountain pine beetle and the use of patch metrics to estimate traversability. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2006-01.

Purpose/Study Area Objective is to examine the effects of fire return rates on the equilibrium age structure of a one-million hectare lodgepole pine forest.

Methods Fire regimes were modelled using Monte Carlo simulation to create a mosaic of ages over one million hectares. These mosaics of ages were used to generate mosaics of susceptibilities to beetle attack. Susceptibility maps were produced for two TSAs in British Columbia, as well as for the whole of BC. In addition, they defined a quality, called traversability, which describes the ability of a beetle population to disperse across a landscape according to defined rules of susceptibility and maximum distance for dispersal through unsuitable habitat. Using each of 40 combinations of susceptibility classifications and dispersal limits, the landscape was categorized as traversable or non-traversable. This represents the suitability of a landscape to allow an incipient beetle population to spread unimpeded across the landscape under consideration. FRAGSTATS patch metrics were

calculated for each of the simulations and these were related to traversability using discriminant analysis. This was then applied to the BC inventory; concordance was high with 93.3% of conditions being correctly classified.

Results It was found that:

- long fire cycles yield an age structure highly susceptible to beetle attack;
- fire suppression reduces the frequency of fires and yields an age structure highly susceptible to beetle attack;
- harvesting one age class reduced the mean susceptibility to beetle attack, and this reduction decreased with increased harvest age and increased fire cycle length.

When fires were limited in sizes < 100 ha, the area was always traversable. For larger fires, traversability declined and for the largest fires (up to one million ha) the area was often not traversable. Harvesting reduced the mean susceptibility and traversability, often substantially. The area most traversable was the area in Tweedsmuir Park and the Lakes Timber Supply Area, where most of the present outbreak is centred.

Gain in Knowledge Identifies areas of difficult and easy spread of mountain pine beetle.

Maclauchlan, L.; Hodge, J. 2008. Integration of GIS analysis and field evaluation to identify young lodgepole pine at risk to mountain pine beetle. FIA–FSP Project M086009, Executive Summary.

Purpose/Study Area Central and northern BC.

Methods By incorporating stand-specific data on beetle incidence and severity collected from 2005 to 2007 with aerial and ground surveys and other stand hazard and risk parameters, they developed a preliminary model to predict future impact in young lodgepole pine stands.

Results The 2005 model applicable to northern and central BC. The 2006 model was somewhat reliable at predicting young attack in 2007. They added southern data in 2007, but all previous data was from the north, so predictive models for southern BC are not yet available.

Gain in Knowledge Cannot judge; final technical report not available.

Maclauchlan, L.; Brooks, J. 2007. Determining susceptibility of young pine stands to the mountain pine beetle, *Dendroctonus ponderosae*, and manipulating future stands to mitigate losses. FIA–FSP Project Y072003, Final Technical Report.

Purpose/Study Area This project quantified beetle-induced mortality in young lodgepole pine stands (20–55-years-old) and estimated the duration and severity of future attack. In 2005 and 2006, 1,206 stands and 2,528 stands respectively were aerially surveyed in seven Districts (Prince George, Vanderhoof, and Quesnel Districts, Nadina, Quesnel, Central Cariboo, and 100 Mile House).

Methods Three levels of sampling: random, stand specific aerial surveys and ground surveys, and the installation and annual evaluation of permanent sample plots.

Results The proportion of stands having some level of mountain pine beetle attack increased from 49% in 2005 to 74% in 2006. The highest average percent attack levels in 2006, red and grey attack combined, were recorded in the Prince George, Vanderhoof, and Quesnel Districts, with 31, 35, and 39% attack, respectively.

Gain in Knowledge Documents the attack levels in young pine.

Maclauchlan, L.; Brooks, J. 2008. Determining impacts and susceptibility of young pine stands to the mountain pine beetle, *Dendroctonus ponderosae*. FIA–FSP Project M085169, Executive Summary.

Purpose/Study Area Appears to continue Y072003 above.

Methods A total of 259 mapsheets, totalling over 2,100 stands, were assessed in 2007 for attack levels.

Results In the 2007 aerial assessment, over 83% of stands surveyed had some level of beetle attack, up from 49% in 2005. In 2007, 16.8% of stands aerially assessed had > 50% total attack (red and grey attack). The highest in-stand attack and percent stands affected occurred in the Kamloops, 100 Mile House, and Quesnel Districts with averages of 47, 42, and 39% total attack,

respectively. Incidence of beetle attack was highest in the SBPS BEC zone. One half of the ground surveys conducted in this zone occurred in the 100 Mile House District, which explains the high level of green attack in 2007. Other zones such as the ESSF and MS, both colder zones, have less current attack. The mild, moist ICH, warm and dry IDF, and moist cool SBS zones all had similar levels of current attack (about 10%).

Gain in Knowledge Location, rather than ecosystem, seems to drive the incidence of mountain pine beetle in young stands at this time. Both the ESSF and ICH zones tend to have more mixed species composition and therefore do not suffer the intensity of attack on stand density. The beetle selects for larger stems in spaced areas.

8.2 Processes

8.2.1 Snag Fall Rates

Huggard, D. 2008c. Effects of salvage options for beetle-killed pine stands on ECA: December 2008 update. A synthesis of currently available data and uncertainties. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC. (see section 8.2.4).

Huggard, D.J.; Kremsater, L.L. 2007. Quantitative synthesis of rates for projecting deadwood in BC forests. FIA–FSP Project SO84000, Technical Report. (see section 8.1.1).

Lewis, K.; Hartley, I. 2005. Rate of deterioration, degrade and fall of trees killed by mountain pine beetle: A synthesis of the literature and experiential knowledge. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2005-14.

Purpose/Study Area The report examines factors determining position of the tree (standing or down) and changes in wood quantity and quality with time since death. It is a synthesis paper relying on scattered published literature, augmented by interviews of forestry workers from the Caribou Plateau.

Methods Literature review and interviews with seven individuals with forestry and/or mill experience in the Cariboo plateau.

Results The synthesis for fall rates is sparse—several interviews and two papers for lodgepole pine. Estimated rates are higher than those of the more complete review of Huggard and Kremsater (2007) and Huggard (2008c).

Gain in Knowledge Provided template for subsequent work by Lewis, particularly Lewis and Thompson (2009).

Lewis, K.; Thompson, D. 2009. Change in wood quality and fall rate of trees up to 10 years after death from mountain pine beetle. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-30.

Purpose/Study Area About 560 lodgepole pines killed by mountain pine beetle were evaluated by dendrochronology to determine the exact year of mortality. The objective was to characterize decay and degradation in factors of wood quality and quantity over time. Fall rates also were determined. Study area was the Quesnel TSA, in the SBSdk and SBSmc3 variants.

Methods Over 550 trees were sampled and successfully cross-dated; 126 of these had been dead for more than 6 years. Range of time since death was 0 to 10 years.

Results At the stand level, 0.25% of the pine that had been dead for 5 years or less had fallen. In stands where trees were killed between 6 and 10 years ago, average fall rate was 28%, ranging from 0 to 60% per plot. Most trees did not fall until at least 8 years after dying. No relationship was found between rate of fall and tree size, although dry sites had a higher rate of tree fall than wet sites. The main determinant of changes in wood properties was change in moisture content. Dependent variables included checking, bluestain depth, saprot, and damage caused by wood borers. Biophysical variables (time-since-death, DBH, height of sample, and growth rate) explained most of the variation in dependent variables. Biogeoclimatic unit and soil moisture regime were not important predictors of decay and degradation, except for development of saprot at the base of the trees. Significant change in the factors noted occurred within the first 1 to 2 years post-mortality and varied with position along the stem and with tree size, followed by a period of relative stability in wood properties until 8 or more years post-mortality, when dead trees began to fall.

Gain in Knowledge Sound relation between wood quality and time since death. Wood properties changed most within the first two years of mortality, with a slower reduction in wood quality thereafter.

Other studies on decay in standing trees (apparent "shelf-life") include:

Breuil, C. 2008. Decay fungi and associated rates of decay in standing trees killed by mountain pine beetle. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-11.

Lewis, K.; Thompson, D.; Hartley, I.; Pasca, S. 2006. Wood decay and degradation in standing lodgepole pine (***Pinus contorta*** var. ***latifolia*** Engelm.) killed by mountain pine beetle. (***Dendroctonus ponderosa*** Hopkins: Coleoptera). Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2006-11.

Sharp, B.; Lewis, K. 2005. Predicting decay and degrade rates in standing and fallen trees killed by mountain pine beetle: A literature review. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2005-15.

8.2.2 Canopy Loss in Pine Snags

Huggard, D. 2008c. Effects of salvage options for beetle-killed pine stands on ECA: December 2008 update. A synthesis of currently available data and uncertainties. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC. (see section 8.2.4)

Huggard, D.J.; Kremsater, L.L. 2007. Quantitative synthesis of rates for projecting deadwood in BC forests. FIA–FSP Project SO84000, Technical Report. (see section 8.1.1)

8.2.3 Light Interception

Coates, K.D.; Hall, E.C. 2006. Implications of alternate silvicultural strategies in mountain pine beetle damaged stands. FIA–FSP Project Y051161, Final Report. (see section 8.1.1 for complete annotation)

Results Class 1 snags were aged 0 to 7 years and had 37.6% light transmission; class 2 snags were 8 to 17 years with 61.4% transmission; class 3 was > 17 years, with 87.8% transmission.

Gain in Knowledge Provides estimates of the understorey light environment in beetle-damaged stands.

Huggard, D. 2008c. Effects of salvage options for beetle-killed pine stands on ECA: December 2008 update. A synthesis of currently available data and uncertainties. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC. (see section 8.2.4).

Huggard, D. 2008b. Predicting light interception in decaying MPB stands. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC. (see section 8.1.1).

Purpose/Study Area To predict interception of light by beetle-killed lodgepole pine trees as they decay and fall. It is a synthesis project that collates relevant data from scattered sources.

Methods The analysis combines information on fall and breakage of snags (from many sources), and loss of shading by branches and dead foliage (mainly from work by Coates and Hall 2006), along with estimates of the uncertainty of these parameters.

Results Uses the synthesized relationships to combine shading by foliage, branches, and trunks of dead lodgepole pine. Converts shading of individual pine stems into shading within a stand by assuming fine-scale, uniform light distribution. Although the assumption is simplistic, it closely matches the results of Coates and Hall's (2006) detailed simulations of light interception by partial green stands after the loss of dead pine (Huggard 2008b, Figure 5).

Gain in Knowledge Provides a first, but well supported, approximation of understorey light as beetle-damaged stands age.

8.2.4 Hydrology

Under large-scale beetle kill, the hydrograph in a snow-dominated watershed is expected to change through four mechanisms altering runoff generation processes: an increase in snow accumulation and melt, a decrease in evapotranspiration, a decrease in channel roughness from large woody debris removal, and extension of the channel network by roads. Studies reviewed are collected under headings representing different constellations of processes.

Overview

Hélie, J.F.; Peters, D.L.; Tattrie, K.R.; Gibson, J.J. 2005. Review and synthesis of potential hydrologic impacts of mountain pine beetle and related harvesting activities in British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2005-23.

Purpose/Study Area A review of large-scale bark beetle epidemics and their possible impacts on hydrology and biochemistry. Identifies and discusses probable impacts of mountain pine beetle infestations in BC, key knowledge gaps, and recommendations for future research.

Methods Literature search.

Results The study concludes that mountain pine beetle in BC will likely significantly change interception and transpiration rates in affected watersheds, thus induce changes in annual water yields, peak flows, and low flows, and create some nutrient loss. Conclusions are largely derived from harvesting studies; authors note there are few studies of bark beetle effects on hydrological and biogeochemical cycles.

Gain in Knowledge No new data offered. Review of Colorado studies suggests greatest effects on hydrology 15 years post-attack: annual water yields 10% greater, peak flows 14 to 22% greater, and low flows about 15% greater (Bethlahmy 1974). Bethlahmy (1975) found that spring runoff in the White and Yampa Rivers of Colorado increased up to 28% after only 30% of the watershed was affected by spruce beetles. Provides a list of 17 items that should be monitored. Suggests that soil and ground water storage ranks most highly, followed by water chemistry. The review augments:

> Holsten, E. 2004. Effects of beetle epidemics and harvesting on stream flow. An annotated bibliography. (covers data through 2003)
>
> Bethlahmy, N. 1974. More streamflow after a bark beetle epidemic. Journal of Hydrology 23:185–189.
>
> Bethlahmy, N. 1975. A Colorado episode: Beetle epidemic, ghost forests, more streamflow. Northwest Science 49(2):95–105.

Water Balance, Rain and Snow Interception, and Snow Ablation

Snow dominates stream and river hydrographs in British Columbia. A first step in evaluating large-scale impacts of beetle attack on hydrology is documenting changes in snow interception and ablation.

Boon, S. 2007. Snow accumulation and ablation in a beetle-killed pine stand in Northern Interior British Columbia. BC Journal of Ecosystems and Management 8(3):1–13.

Purpose/Study Area The study assesses the impact of beetle infestation on ground snow accumulation and snow ablation in dead, alive, and clearcut stands in the SBS of the Nechako Plateau.

Methods Measures were acquired in three stands: alive (green trees), red- to grey-attack, and salvage logged (clearcut, now rangeland). Point-based daily snow ablation amounts and rates for each stand were calculated using the energy balance equation and daily averages of meteorological data (Onset® Weather Station). Snow depth was measured on transects in each cardinal direction from the meteorological station.

Results The paper reports preliminary results of a continuing study (see Boon 2008). Snow depths and snow water equivalents differed significantly between the three stands, with clearcut, dead, and alive having the most to least. Modelled and measured snow water equivalents were closely similar. As beetle-killed trees progress into grey attack, they drop needles, thereby decreasing interception of precipitation by up to 50% above pre-infestation levels. This exceeds the reduction of evapotranspiration between 6 and 39% observed from sub-boreal watersheds subjected to harvesting alone (review by Plamondon 1993).

Gain in Knowledge Beetle infestation may increase net precipitation. Because any such increase is either stored or moved through the watershed, salvage logging can sometimes expand the area of wet ground upon which operation of forestry equipment is difficult or impossible before freeze-up (Rex and Dubé 2009).

> Plamondon, A.P. 1993. Influence de la coupe sur l'écoulement annuel, le debit de pointe et la qualité de l'eau. Centre de Recherche en Biologie Forestière, University of Laval et Ministère des Forêts du Québec.

Boon, S. 2009. Impact of mountain pine beetle infestation and salvage harvesting on seasonal snow melt and runoff. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-24.

Purpose/Study Area The study analysed 2 years of field data collected under three different canopy types (alive, dead–grey attack, clearcut) on the Nechako Plateau in the dry, cool Sub-Boreal Spruce (SBSdk). The intent was to model hydrological changes in a landscape composed of a complex mosaic of clearcuts, regenerating, dead, and live older stands.

Methods Snow interception and snow ablation under the three canopy types were sampled (see Boon 2007). Meteorological measurements intended to drive the model were acquired by Campbell Scientific and Onset meteorological stations.

Results The author reports, "Results of the 2004 and 2017 scenario runs cannot be physically explained. This suggests an error in either the model parameterization or land cover information." Interception and ablation were more straightforward:

Table 3. Snow interception and ablation under three canopy types.

	Clearcut	Dead	Live
Snow Depth (deeper snow fall)	100%	94%	89%
Snow Depth (less total snowfall)	100%	85%	70%
Ablation (less snowfall mm/d)	12.8	11.9	13.2

In years of high snowfall, dead stands behaved similarly to alive and clearcut stands as large snowfalls exceeded the interception capacity of the canopy. In low to average snow years, distinct differences in snow accumulation in dead stands were attributed to needle loss and canopy reduction. Climate change may increase the frequency of years of low snowfall. Continuous snow depth measurements in the dead and clearcut plots indicate that smaller snowfalls, and a proportion of each large snowfall, are intercepted by the dead forest canopy, reducing the range of individual snowfall amounts relative to the clearcut.

We found one comparable study (Schmid et al. 1991): net precipitation (precipitation gauges plus SWE) for each site of small group infestation did not differ significantly from controls over a 4-year period. Standing trees (retained needles for first two years) apparently intercepted as much precipitation as the controls.

Impacts were anticipated at the watershed level. Although relevant meteorological measurements were acquired they could not be effectively scaled up. The researcher notes that cause of the error—model parameterization or land cover information—could not be discerned. Boon (2007) reported measured and modelled amounts of SWE in each of the three stands and found good agreement. We suspect inaccurate forest cover information prohibited scaling up.

Gain in Knowledge Affirms dead canopies intercept snow and modify ablation. Results likely could be scaled up with appropriate forest cover. Huggard (2008c) provides a more complete review of snow interception and ablation (see Hydrological modelling and ECA below).

Schmid, J.M.; Mata, S.A.; Martinez, M.H.; Troendle, C.A. 1991. Net precipitation within small group infestations of the mountain pine beetle. USDA Forest Service Research Note RM-508.

Carlyle-Moses, D.E.; Burles, K.A. 2009. Measurement and modelling of mountain pine beetle impacts on the annual forest water balance. FSP–FIA Project M086035.

Purpose/Study Area Winter and growing-season water stores and fluxes (SWE in winter, canopy interception, throughfall and stemflow, moss layer interception during growing season) were measured for 2 years to assess hydrologic impacts of the beetle and associated management activities. Measurements were acquired at Mayson Lake on the Thompson Plateau, where R. Winkler and D. Spittlehouse (BC MoFR) have a long-term snow hydrology research program in the Upper Penticton Creek Watershed.

Methods Five stands were studied:

1. a recently attacked mature lodgepole stand where most infested trees had been harvested;
2. a recently attacked mature lodgepole pine stand that was not then harvested;
3. an older clearcut with pine regeneration averaging 3 m;
4. an unmanaged 8-m tall juvenile stand; and
5. a stand similar to stand 4 in its species composition, age, and height, but which had been thinned and pruned.

Each stand had throughfall gauges, stem flow collectors, interception lysimeters and soil moisture probe access tubes. SWE was derived from 32 sample points in each stand.

Results Canopy interception loss was a significant component of the growing-season water balance in healthy mature lodgepole-dominated stands (29% of rainfall in a typical season). The loss did not change during the green or red attack stages relative to healthy stands. Selective cutting of lodgepole pine trees did not appear to impact the quantitative importance of canopy interception loss from mature stands (no threshold value apparent). Burned stands without foliage but with snags had significantly smaller canopy interception loss values than mature green or red attack stands. Dead stands intercepted 9% of growing season rainfall. The bryophyte layer was an important interface between the forest proper and the underlying soil. Snow melt rates and SWE values under green and red attack were not different from those under healthy canopy conditions. Burned stands tended to behave more like clearcuts than mature, foliated stands with regards to snow melt rates and SWE values.

Gain in Knowledge Transpiration and direct evaporation from the soil accounts for a little over half of the total evapotranspiration output from mature forest stands, while canopy interception loss accounts for a little less than half. Thus, total evapotranspiration may drop by 40 to 50% under green and red attack stages. Removing trees and bryophyte layers will increase the volume of water entering the soil.

Teti, P. 2008. Effects of overstorey mortality on snow accumulation and ablation. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-13.

Purpose/Study Area The project used physical stand characteristics to predict snow accumulation and snow ablation rates of growing, managed stands and deteriorating natural stands. Six groups of plots were established in the Vanderhoof, Quesnel, Chilcotin, Central Cariboo, and Kamloops Forest Districts.

Methods Plot characteristics were documented by detailed surveys of tree and coarse woody debris, and by wide-angle canopy photos from which solar radiation transmittances and other optically derived parameters were calculated. Snow accumulation and ablation rates were documented by ground surveys and aerial photography in 2006 and 2007.

Results Estimated standard deviations of radiation transmittance varied by a factor of 12 between plots. In four of the six groups where snow accumulation data were most reliable, snow accumulation and ablation were highest in plots that had been clearcut or burned within the last 10 years, but decreased to values similar to undisturbed stands within 35 years. Snow accumulation was lowest in old foliated (living) stands and managed stands older than 25 years. Snow accumulation in beetle-attacked stands relative to nearby cutblocks < 10 years old ranged from 77 to 90% of cutblock values. In four of the six groups, snow ablation rates were highest in stands that had been logged within the previous 15 years. Ablation rates in managed stands more than 30 years old were similar to those in old intact forests.

Gain in Knowledge Results suggest that logging dead pine stands increases the volume and rate of spring snowmelt for about 15 years. To estimate transmittance, sample size requirement using wide-angle canopy photography varies from six to more than 40, depending on the spacing and sizes of stems. Aerial photo methods for estimating radiation transmittance were initiated under a new project under the mountain pine beetle project #7.23, "Novel aerial photography as an aid to sampling secondary structure in pine stands" that is underway.

Water Quality

Brown, S.; Lavkulich, L.; Schreier, H. 2009. Water quantity and quality related to rates of pine beetle infestation and salvage logging: A regional comparison. MPB Project #7.31.

Purpose/Study Area This project provides an initial spatial and seasonal assessment of water quality in beetle-attacked regions across the province in terms of physiographic, geologic, and climatic features. Specific goals were to determine how geology, dominant runoff processes, forest cover/pine cover, soil characteristics, road density, and the beetle affect water chemistry. Study

sites were in watersheds of the Quesnel River, Lower North Thompson River, Nicola River, Okanagan River, Kootenay Lake, and St Mary River.

Methods Stream water quality from 15 watersheds in BC was compared over a 1-year seasonal cycle to determine how watershed characteristics, road and forest conditions affect water quality. Water quality variables examined included: nutrients (NO3, NH4, Cl, PO4, total organic carbon [TOC]), metals (Al, Cu, Zn, Mn, Ni) and physical (turbidity, suspended sediment, electric conductivity [EC]).

Results As expected, TOC, turbidity, Al, and other less soluble minerals all showed significant increases during freshet and declined during base flow while EC, Ca, Mg, and other soluble minerals or salts declined during the freshet and became more concentrated during base flow (lower flows translate to less dilution of soluble minerals and salts). Electric conductivity varied significantly between regions reflecting geological differences. In terms of watershed characteristics:

- Negative correlations were found between geology (e.g. % granodiorite–granite) and soluble minerals and salts (geology in these watersheds played a dominant role in influencing the water quality conditions).
- Positive correlations were found between vegetation parameters and TOC; specifically % forest cover and % pine cover, with pine having a stronger relationship. TOC is not influenced by geology, but reflects litter availability and decomposition.
- No significant trends were found with either historic (1999–2005) or recent (2006–08) beetle infestation. However the good relationship with percent pine suggests that longer term monitoring may improve the predictive capacity.
- Turbidity levels were of insufficient range to show the impact of land cover, but even with a limited data set, turbidity appears related to the number of road crossings.
- The litter layer was found to be hydrophobic under a closed canopy.

Gain in Knowledge Primarily affirmed expectations. Relationships with mountain pine beetle were weak, but the strong relationship with percent pine cover suggests that longer-term monitoring may show differences and improve the predictive capacity. Application of the FREP water quality protocol to assess impact of road crossings on suspended sediment load provides a cumulative assessment that can be applied by non-specialists at the level of individual cutblocks. This project's assessment at the watershed scale suggests the FREP approach relates well to water quality and watershed characteristics. Cumulative sediment monitoring (e.g., suspended sediment traps) would likely be required to develop stronger relationships with watershed characteristics, such as the beetle, road density, and harvesting, to stream sediment loads.

Hydrologic Modelling and ECA

Equivalent clearcut area (ECA) is a simple index used to describe a developing stand or block in terms of its hydrological equivalent as a clearcut. As a new stand develops, the hydrological impact on a site is reduced. The rate of reduction is expressed in proportion to the height of the second growth. The index has limitations and more direct hydrologic modelling studies (Alila, Moore, Weiler, and others reviewed below) may someday supplant the need for ECA. Currently, the numerical modelling studies require some form of canopy recovery relation similar to ECA.

Alila, Y. 2006. Forest management in interior British Columbia: Moving beyond equivalent cut area. FIA–FSP Project Y052294, Annual Technical Report. (no subsequent year found)

Purpose/Study Area The study intended to combine findings for several southern interior watersheds by supplementing field-based results with long-term numerical modelling. Specific objectives were to:

- quantify effects of forest management on hydrology and channel morphology in a forested, subalpine watershed (Cotton Creek) that experiences both radiation and rain-on-snow driven snowmelt; and
- combine the results with previous studies to better understand the influence of basin physiography including topographic relief, size, soil, and vegetation attributes on hydrologic and geomorphic response.

Only the first objective is addressed in this report.

Methods Cotton Creek is well instrumented to provide relevant meteorological data and stream discharge. Methods focus on snowmelt, because in snow-dominated catchments snowmelt has the greatest influence on stream flow response. Snow depth, SWE, and temperature were collected at 19 sites stratified by elevation aspect and forest cover. Regression models were developed.

Results This report of early results found that the regression model estimating SWE by elevation, aspect and forest cover was simple and predictive.

Gain in Knowledge Multiple cheap sensors acquire air temperate at greater spatial resolution than does the same expenditure on more expensive sensors or weather stations, permitting better prediction of snow melt in a watershed. The main stream flow responses in the subcatchments as well as snow accumulation and snow melt were captured, but accuracy could be improved.

Alila, Y. 2008. Peak flow and water yield responses to mountain pine beetle infested and salvage logged watersheds in the Kootenays. FIA–FSP Project M085276, Final Annual Report.

Purpose/Study Area Applies a distributed hydrology model to quantify the effects of beetle infestation and treatments on stream flows in Cotton Creek Experimental Watershed near Cranbrook. The objective is to quantify effects of various salvage logging scenarios on the water yield and peak flow regimes. The report notes studies at Baker Creek in the northern Cariboo (Teti's study area; we found no reports directly referencing work there by Alila).

Methods Numerical modelling does not require the expensive, long-term data collection of paired watershed studies. Instead, it takes a shorter period of extensively monitored hydro-climate data to develop and calibrate watershed model applications and applies them in long-term simulations of synthetic climate data to quantify the effects of alternative forest disturbance scenarios. The model employed is DHSVM of Wigmosta et al. (2002), driven by synthetic climate data to create a 65-year stream flow time series from shorter-term existing data.

> Wigmosta, M.S.; Nijssen, B.; Storck, P.; Lettenmaier, D.P. 2002. The distributed hydrology soil vegetation model. Pages 7–42 *in* V.P. Singh and D.K. Frevert, eds. Mathematical models of small watershed hydrology and applications. Water Resource Publications, Littleton, CO.

Results Simulations suggest:

- for a given proportion cut, the peak flow regime is much more sensitive to harvesting at higher elevation bands within the same watershed;
- under a snowmelt-dominated peak discharge regime, post-harvest change in flow relative to control is consistently positive and increases with increasing return period, with no apparent asymptotic limit (but appears to be an overestimate);
- changes in flood magnitude translate into marked changes in flood frequency so that the larger the magnitude of a flood event, the more frequent it may become; and
- results are difficult to extrapolate (response of the peak flow regime to forest harvesting is very sensitive to spatial scale, climate, and topography).

Gain in Knowledge Paired watershed studies evaluating the effect of insect infestation (Mitchell and Love 1973; Bethlahmy 1975; Potts 1984) or of salvage harvesting (Cheng 1989; Moore and Scott 2005) on stream flow characteristics experienced disturbance < 35% so do not apply to large-scale disturbances. The strong effect of upper elevation, large-scale harvesting (> 30%) in snow-dominated systems is likely general.

Alila, Y.; Kuraś, P.K.; Schnorbus, M.; Hudson. R. 2009. Forest and floods: A new paradigm sheds light on age-old controversies. Water Resources Research 45:W08416.

Purpose/Study Area This is an extensive and sound examination of influences of forest harvesting on magnitude and frequency of floods. It relies on published data from two well-studied watersheds: Fool Creek in the Fraser Experimental Forest in Colorado and WS1 and WS2 of H.J. Andrews Experimental Forest in Oregon. The two objectives are to:

1. illustrate how commonly applied analyses have proven misleading; and
2. illustrate how frequency-paired event analysis can inform long-standing controversies.

Methods Methods are necessarily statistical and model based; in particular they are designed to expose how extremata of distributions can lead to erroneous conclusions (a finding common in climate change modelling). Most simply, they evaluate the reliability of conclusions derived from comparing peak flow following harvest to an expected sample of flows in the absence of harvesting, and evaluate conclusions derived from chronological pairing of events derived from the same rainstorm or snowmelt freshet.

Results Major findings are:

- frequency based and chronological pairing can lead to different interpretations of outcomes;
- treatment of the tails of frequency distributions greatly influences interpretation of outcomes;
- harvesting can affect large floods more so than small or medium floods; and

- recovery times may be poorly estimated by the most common forms of analysis.

Gain in Knowledge Analytical methods can be improved. Changes in forest cover can influence peak floods and large areas, contrary to much conventional thinking. Basin-specific conditions hinder ready generalization.

Coops, N.C.; Weiler, M. 2008. Equivalent clear cut area thresholds in large-scale disturbed forests. Progress Report. FIA–FSP Project Y081171.

Purpose/Study Area This is an attempt to characterize tree- and stand-level estimates of snow interception and ablation over large areas. The study focuses on a 200-km transect between Quesnel and the Vanderhoof area. The transect connects existing research sites in the Baker Creek watershed (sites of P. Teti and Y. Alila) to sites near Vanderhoof (sites of P. Teti and S. Boon) along a 400-m wide transect. The purpose is to use remote sensing technology (LiDAR) to predict structural attributes of healthy and disturbed stands, and combine these data with field measurements of snow accumulation and melt. The goal is to relate remotely derived parameter(s) that statistically explain differences in snow accumulation and melt to data from forest cover maps to derive new guidelines for ECA calculation in large-scale disturbed areas.

Methods Four environments were recognized: clearcuts, young regeneration, red stands, and grey stands. Instrumented plots and snow surveys (e.g., Boon 2007, 2008; Teti 2008) were used to relate canopy structure to snow accumulation and ablation. LiDAR data and digital imagery were acquired using the TRSI Mark II discrete return sensor attached to a helicopter platform. Data pre-processing was evaluated in the Fraser Valley by creating a digital elevation model then subtracting it from discrete return data to create height estimates above the ground surface. That allows LiDAR to compute metrics sensitive to forest structure: maximum height, crown area, canopy cover, and canopy height profiles.

Results Interim results include preprocessing and demonstration of a negative relationship between visual estimates of attacked trees (red and grey attack) and LiDAR estimated cover ($r^2 = 0.47$).

Gain in Knowledge Proof of concept demonstrated with low r^2.

Grainger and Associates Consulting Ltd and Streamworks Unlimited. 2008. Chase Creek Hydrological Risk Assessment.

Purpose/Study Area The study assessed risk to residences, businesses, property, and infrastructure along the Chase Creek mainstem (Thompson Plateau) due to potential flooding hazards related to beetle infestation and salvage harvesting of attacked stands in the watershed.

Methods The report uses extensive previously published materials on Chase Creek watershed conditions and various models to examine effects on stream flow. It notes various ECA calculations have been completed at various times for Chase Creek watershed. Most recently, Huggard (2008c) completed ECA analyses for Chase Creek for initial watershed conditions at the end of 2005 and again at the end of 2007. Much of the modelling uses Huggard's approach, although other methods are incorporated.

Results In the Chase Creek watershed, beetle-induced tree mortality and salvage logging have likely increased Equivalent Clearcut Area (ECA) values from between 20 to 25% at the start of widespread beetle attack around 2000, to 45% near the end of 2007, or within a few years thereafter. Without further salvage logging, ECA levels are not expected to increase appreciably, and in about 25 years will decrease to a level where significant incremental peak flow effects are unlikely to be experienced (< 20% ECA). Initial ECA values for the types of dead pine stands in Chase Creek watershed are significantly lower than clearcut ECAs, and never get as large as clearcut ECAs.

The estimated expected flood frequency shift due to the mountain pine beetle and salvage effects would cause the pre-beetle 50-year return period flood to occur, on average, every 20 years. All other magnitude/return period floods also shift accordingly, and hence are 2.5 times as likely to occur.

Gain in Knowledge Salvage logging since 2000 in the watershed has likely increased the ECA in the upper watershed area contributing to freshet peak flows to 45% (from the level it would have reached, ~ 35%, had no salvage harvesting occurred in the watershed). The increase of ECA with incremental salvage harvesting is expected to last for at least 10 to 15 years, before planted stand re-growth results in watershed ECA values similar to those which would have existed had no salvage harvesting occurred. Authors do not suggest the "no-salvage" option is the most desirable. Leaving the entire beetle-attacked watershed untouched would not have allowed other important management objectives to be realized, such as wood supply, employment, crown revenue, and future commercial timber development.

Huggard, D. 2008c. Effects of salvage options for beetle-killed pine stands on ECA: December 2008 update. A synthesis of currently available data and uncertainties. Prepared for D. Lewis, BC Ministry of Environment, Kamloops, BC.

Purpose/Study Area The study synthesizes data on the effects of salvaging or not salvaging beetle-killed stands on equivalent clearcut area (ECA) value of a stand. Data are synthesized from scattered sources, but applied in the Kamloops region.

Methods The project evaluates findings locally, treating four relations needed to predict the immediate and longer-term ECA effects of stand management options:

1. relationships between the height and canopy cover of regenerating conifers and ECA;
2. contributions from dead pines over time, including their fall rates and decreasing canopy cover;
3. stand components expected to be unaffected by the beetle: understorey and non-pine overstorey; and
4. expected growth and mortality of surviving non-pine canopy trees, saplings, and seedlings, or planted seedlings and natural ingress.

Contributions to reducing ECA from non-pine overstorey, dead pine, saplings, seedlings, and natural or planted regeneration are combined to predict the ECA value of stands that are clearcut-salvaged and planted, partially salvaged, and unsalvaged. ECA is calculated immediately after disturbance and through time for three example stand types. Uncertainties associated with each parameter are estimated and followed through the analysis to determine the uncertainty associated with the ECA predictions.

Results Initially, unsalvaged stands have a lower ECA value than clearcut-salvaged stands, due mainly to non-pine canopy trees and the contributions of dead pine snags. Planted salvaged stands are expected to recover more quickly. Which option produces the least total ECA effect over time depends on many factors, but the amount of non-pine species in the canopy and growth rates had large effects. "Partial salvage" produced less ECA effect than clearcut salvage when planted trees grew well, but somewhat greater total ECA if retention lowered growth rates considerably.

Gain in Knowledge Provides a useful decision tree for management options in face of beetle kill. Methods of analysis are robust and quantify uncertainty well. Synthesis suggests a near-linear relationship between ECA and tree height, reaching a value of about 10 to 11.5% ECA at 12 m, followed by a slow decline towards an ECA of 0 in taller stands. Empirical measures of canopy closure with height are summarized. ECA as a function of canopy closure is derived from studies by Winkler et al. (2004), Beaudry (2006, 2007), Boon (2007), and Teti (2007). Effects of understorey and non-pine canopy are included in estimates of ECA. Example projections of ECA in salvaged, partially salvaged and unsalvaged stands are included.

Beaudry, P. 2006. Snow surveys in supply block F, Prince George TSA January to April 2006. Contract report by P. Beaudry and Associates Ltd. for Canfor, Prince George, BC.

Beaudry, P. 2007. Snow surveys in supply block F, Prince George TSA, January to March 2007. Contract report by P. Beaudry and Associates Ltd. for Canfor, Prince George, BC.

Boon, S. 2007. Snow accumulation and ablation in a beetle-killed pine stand in Northern Interior British Columbia. BC Journal of Ecosystems and Management 8(3):1–13.

Teti, P. 2007. Solar radiation and snow ablation in natural and managed pine stands. Pages 17–18 *in* T. Redding, ed. Mountain pine beetle and watershed hydrology workshop: Preliminary results of research from BC, Alberta, and Colorado, July 10, 2007, Kelowna, BC. FORREX, Kamloops, BC.

Winkler, R.; Gluns, D.; Golding, D. 2004. Identifying snow indices for forest planning in southern British Columbia. Pages 53–61 *in* K. Elder, ed. Proceedings of the Western Snow Conference, Richmond, BC, April 19–22, 2004.

Kuraś, P.K.; Alila, Y.; Weiler, M.; Winkler, R. 2008. Forest road and harvesting impacts on the peak flow regime of a snow-dominated catchment. FIA–FSP Project M086039, Poster.

Purpose/Study Area The study area is 241 Creek in the Upper Penticton Creek Watershed experiment. The objective was to use DHSVM (see Alila 2008) to evaluate sensitivity of stream flow metrics to pre-existing, current and planned harvest scenarios, with and without roads.

Methods Instrumentation in the study area provided sufficient meteorological data to drive simulations using long-term synthetically generated meteorological data, producing stream flow time series of 100-year duration at an hourly resolution. Each harvest scenario was driven by vegetative recovery (i.e., ECA) as in Alila (2008), generating a stationary flood frequency response

reflective of the first few years post-treatment. The sample annual maximum series from each time series was used to estimate the frequency distribution of the annual maximum peak discharge for each particular scenario. The generated peak flow regime for each scenario and stream flow metric was quantified using flood frequency analysis of the simulated annual maximum flood series using the generalized extreme values distribution. Note that the same factors that drive ECA (vegetative recovery) also drive the more complex numerical modelling.

Results Prior (20% harvest area) and current (30% harvest area) operational harvest conditions in the watershed had no significant effect on peak flow regime. Roads mitigated effects of harvesting by transporting water out of the basin. Proposed harvesting in the watershed (50% harvest area) had a statistically significant effect on flood peaks with recurrence intervals ranging from 10 to 100 years for all three stream flow metrics (hourly, daily, weekly), implying substantial ecological, hydrological, and geomorphological consequences of peak annual discharge. Peak flow regimes were fairly tolerant of harvesting up to 30%, but effects past about 30% could induce significant changes.

Gain in Knowledge For this watershed, peak flow was little affected by harvest levels of up to 30% of the watershed but had negative consequences by 50%. Roads associated with harvesting had relatively little impact, and can serve to mitigate peak flow effects if they redirect water out of the basin. Note, Alila (2008) did not incorporate roads.

Moore, R.D. 2009. Cotton Creek Phase II: Multi-scale, spatially explicit studies of mountain pine beetle impacts on watershed function. FIA–FSP Project Y092214, Year-end Report.

Purpose/Study Area The study is a continuation of "Forest management in interior British Columbia: Moving beyond equivalent cut area. FSP Annual Report, Project Number Y052294." Location is the Cotton Creek watershed in the Kootenays. The objective is to improve ability to predict, at multiple spatial and temporal scales, the cumulative influences of forest disturbance (specifically insect infestation) and post-disturbance forest management responses. There are two specific components:

1. runoff dynamics and the influences of forest disturbance and management; and
2. processes governing the downstream transport and distribution of water, nutrients, heat, sediment, and woody debris.

Methods The Cotton Creek watershed is well instrumented and documented in a GIS. Snowpack drainage was measured by lysimeters. Spatial patterns of modelled average peak snow accumulations (1 April) and melt rates modelling by DHSVM [see Alila 2008] above] were compared to field measurements in relation to the effects of elevation, aspect, and forest cover (presence/absence).

Results Conclusions are interim. Substantial melt can occur at the base of the snowpack throughout the winter, even when the snow surface remains frozen. DHSVM successfully reproduced the major spatial patterns derived from snow surveys. The modelled effect of elevation on snow accumulation and snow melt was similar to the observations. Of the three main factors, aspect was modelled least accurately. The contrast between forest sites and clearcuts was modelled well in a snow-rich year and less satisfactorily in a low-snow year.

Gain in Knowledge Melt at the snowpack base was unanticipated and has implications for modelling snow melt and potential feedback to runoff generation. DHSVM performed satisfactorily for most features evaluated.

Rex, J.; Dubé, S. 2009. Hydrologic effects of mountain pine beetle infestation and salvage-harvesting operations. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2009-05.

Purpose/Study Area The study examined the process of "watering-up"—a term used to refer to an increase in elevation of the groundwater table following harvesting. Study sites were in SBS and ESSF of the Vanderhoof Forest District. Forestry practitioners in the Vanderhoof Forest District had reported an increase in groundwater storage, and a replacement of summer ground (dry, firm soil) with winter ground (wet, loose soil), upon which operation of forestry equipment is difficult or impossible before freeze-up. The broad objective was to identify a set of risk indicators to predict the risk of summer-ground loss at the watershed level within the Vanderhoof Forest District.

Methods Risk indicators were selected from available GIS information, aerial photographs, and local knowledge. To make these indicators operationally applicable in forest planning, general information such as watershed aspect, slope, and soil type were used. Indicators were selected during an iterative process that included model refinement, prediction, and field verification over two years and a post-hoc assessment of field information to select the indicators that explain most data variability.

Results The most effective indicators for predicting the risk of wet ground areas at the watershed level were lodgepole pine content, understorey, drainage density, sensitive soils and the topographic index—all of which are available from provincial databases. Wet ground areas were found to be associated with beetle-affected forest stands. Distribution of these locations was due to a combination of climate, beetle infestation, and watershed physiographic conditions including slope and soil type. Climate, particularly precipitation levels in winter and summer, had the most significant effect on soil moisture conditions. Wet ground areas were observed during wetter periods in watersheds with pre-existing conditions (e.g., lack of understorey and/or restricting soil layers) that made them prone to losing summer ground. Wet ground areas are not solely a function of canopy loss due to the beetle infestation; rather, they are a cumulative response to many factors that enhance delivery of precipitation to the ground and its retention within the soil profile. Salvage logging can contribute to expanding wet ground area through canopy removal and soil disturbance effects on natural surface drainage patterns. The post-hoc assessment risk model effectively predicted field conditions at the 17 sites inventoried during the 2006 and 2007 sampling program.

Gain in Knowledge Salvage logging can expand the area of wet ground. In the Vanderhoof Forest District, the ratio of summer to winter precipitation has increased significantly since 1997; summer months between 1997 and 2007 received more precipitation than they did from 1980 to 1996. That trend could continue. Empirically based management recommendations to aid forest managers dealing with the beetle epidemic were developed. The list of indicators identified is readily available and can be used to guide operations management at the watershed and site levels.

Schnorbus, M.; Bennett, K.; Werner, A. 2010. Quantifying the water resource impacts of mountain pine beetle and associated salvage harvest operations across a range of watershed scales: Hydrologic modelling of the Fraser River Basin. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Information Report BC-X-423.

Purpose/Study Area The study assessed hydrologic sensitivity to the effects of the beetle and projected effects of varying levels of salvage harvest of pine within the Fraser River basin. The study area is the Fraser River drainage basin (230 000 km^2).

Methods Because of the large area of assessment, the Variable Infiltration Capacity (VIC) hydrology model was used. The VIC model is a spatially distributed macro-scale hydrology model that has been applied at a resolution of 1/16-degree (approximately 27–32 km^2, depending upon latitude) and used to quantify stream flow impacts for 60 sub-basins ranging in area from 330 to 217 000 km^2. The local and regional sensitivity of stream flow to beetle and harvest disturbance was assessed using seven scenarios: pre-infestation baseline (forest cover and beetle disturbance ca. 1995); current (forest cover and beetle disturbance ca. 2007); and five hypothetical scenarios of increasing disturbance severity (from baseline) ranging progressively from 100% kill of mature pine plus 0, 25, 50, 75, and 100% harvest (by area) of killed pine. As the hypothetical scenarios consider harvesting only of beetle-killed pine, the 100% harvest scenario does not imply the complete removal of forest cover in any region.

Results Results are preliminary and focus on impacts to the annual maximum peak flow regime. As anticipated, peak flow impacts become more severe as severity of disturbance increases. For instance, relative changes (from baseline) in the magnitude of the 20-year peak flow event range over the studied basins from no change to 1) 8% for current forest cover, 2) 8% for 100% beetle-kill (0% harvesting), 3) 46% at 25% harvesting, 4) 91% for 50% harvesting, 5) 130% for 75% harvesting, and 6) 172% for 100% harvesting of dead pine.

Gain in Knowledge Unclear; no surprises and no way of evaluating accuracy. The study illustrates the applicability of existing techniques to hydrological events over large areas.

Wei, A. 2007a. Using GIS and time series analysis to evaluate impacts of large-scale forest logging on hydrology in the BC interior. FIA–FSP Project M075036, Year-end Summary.

Purpose/Study Area A 1-year study of two large neighbouring watersheds, the Bowron and the Willow in the Central Interior of British Columbia (respective areas, 3590 and 3110 km^2). The study used long-term historical data to evaluate whether large-scale salvage logging had significant impacts on hydrological variables (peak flow, mean flow, and low flow) in either watershed.

Methods Stream flow data from two hydrometric stations (one for each watershed) were used to calculate hydrological variables of mean, peak, and 7-day low flows. Climate data (precipitation and temperature) were acquired from weather stations in Barkerville and at Prince George airport. Annual forest harvesting records for both watersheds were used to calculate equivalent clearcut area (ECA).

Results Forest harvesting in the Willow watershed significantly increased mean and peak flows for annual and spring snow-melt (April to June) periods, but had no significant changes to low flows in all study periods. Hydrological variables in the Bowron watershed showed either no significant response to large-scale logging or were inconclusive. Note, Alila (2008) also reported strong basin-specific effects.

Gain in Knowledge Hydrological responses to forest harvesting in large watersheds are not readily generalized. Different responses in the two watersheds were attributed to differences in topography, forest disturbance characteristics, and climate.

Weiler, M.; Scheffler, C.; Tautz, A.S.; Rosin, K. 2009. Development of a hydrologic process model for mountain pine beetle affected areas in British Columbia. University of Freiburg, Institut für Hydrologie 2009 No. 44.

Purpose/Study Area The overall objective was to estimate impacts of land cover change on average peak flows for all third-order (1:50 000) watersheds in the Fraser River watershed. The goal was to provide a model applicable to all watersheds and in particular to ungauged basins throughout the Fraser Basin. There were three sub-objectives:

1. map peak flow generation areas and their contribution to peak flow for each 3rd-order watershed within the Fraser Basin;
2. simulate scenarios of current and future land-use to predict the relative changes in peak flow in each assessment unit; and
3. propose and test a methodology to assess the cumulative effects of these changes with the Fraser River Basin.

Methods The model is structured to identify and assess those areas in a watershed that are most influential in changing peak flow response in the main river channel. It consists of four modules:

1. Climate Input Module: spatially predicts peak-flow-generating climate input for each defined watershed;
2. Land Cover Modification Module: modifies climate input in relation to vegetation cover;
3. Runoff Generation Module: uses dominant peak-flow-producing hydrologic processes to simulate runoff contribution to stream during peak flow; and
4. Stream Routing Module: maps travel time from source to watershed outlet.

Three scenarios were addressed:

1. no beetle effects (baseline);
2. all pine killed, 0% salvage;
3. all pine killed, 100% salvage.

During simulation all watersheds received the same scenario.

Results Reducing standing pine cover or removing forest cover generally increases peak flow. However:

- Equal area reductions in vegetation do not lead to the same peak flow increases and suggest scale effects from 3rd- to 6th-order watersheds.
- The degree of peak flow increases due to land use changes is related to watershed size. Peak flow increases between 23 and 88% have a higher probability at higher watershed scales.
- Harvesting activities have a greater impact on peak flows than does grey attack; similar to findings of the Forest Practice Board (2007b).

Gain in Knowledge Provided one has sufficient faith in the model, it can be used to suggest best management scenarios—for example, it could determine where in a watershed a beetle-infested forest can be logged while minimizing the effects on peak flow. The results provide a direct and spatially explicit link at a relevant scale (0.4–16 ha) to relate forest management to hydrological processes.

FPB. 2007b. The effect of mountain pine beetle attack and salvage harvesting on streamflow. Special Investigation, FPB/SIR/16–March 2007.

Riparian Areas

Removing trees from riparian areas during salvage logging or other harvest has several potentially significant consequences. The most direct are likely reduced shading, thus increased stream temperature (see stream temperature and fish below) and modified levels of woody debris into the stream. Woody debris is a dominant control of channel morphology in small streams throughout British Columbia. In the absence of mass wasting, woody debris inputs to small channels in stable, low gradient watersheds are dominated by riparian sources.

Hassan, M.; Hogan, D.; Bird, S. 2008. Mountain pine beetle impacts on channel morphology and woody debris in forested landscapes. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-07.

Purpose/Study Area The study used 18 watersheds in the SBS and SBPS BEC zones to assess watershed-scale impacts of mountain pine beetle by comparing channel conditions and the woody debris budget in watersheds infested by the beetle with those from similar old-growth forests having pre-infestation channel and riparian data. The objective was to determine watershed-scale impacts of the beetle by comparing channel conditions and the woody debris budget in watersheds infested by the beetle to those from similar old-growth forests with pre-infestation channel and riparian data.

Methods To minimize effects of the natural variability, watershed triplets were selected by grouping watersheds into study regions then selecting triplets that minimized the dissimilarity amongst both watershed- and channel-scale morphometrics. Woody debris budgets were used to link lodgepole pine mortality to stream channel and landscape-level conditions.

Results Lodgepole pine was most often absent from riparian areas of the 18 watersheds studied. Canopy layers were dominated by either sub-alpine fir or white spruce with alder and willow common in the shrub layers.

The worst-case scenario (100% mortality) for riparian areas with lodgepole were projected to increase input rates of woody debris about 3.7 times over pre-infestation rates, raising net storage in stream channels until about 2050. Length of the peak period debris input (tp) was set at 15 years and assumed equivalent to the average time for lodgepole pine snags to fall. Review of Huggard (2008c, Figure 4.1) suggests it is likely shorter, resulting in more concentrated input and larger effect. On average, the predicted input of woody debris transferred following beetle infestation is expected to be about 10% of that derived from a stand-replacing event. The increase in woody debris storage resulting from lodgepole pine mortality is then relatively minor compared to the undisturbed range of wood debris dynamics. This projection appears contrary to empirical findings of Wei (2009), but incorporates a larger sample size.

Over the short term (between 1998 or 1999 and 2006), there was no change in the number of log jams in any of the channels in either the SBPS or the SBS zones. The relatively small changes in wood storage volumes may induce some localized channel instability but are not expected to alter channel morphology at the landscape scale.

Gain in Knowledge Quantified woody debris budgets for small channels. Authors suggest little effect that cannot be handled by current regulations, but other studies suggest regulations have not been well employed (e.g., Nordin et al. 2008; Rex et al. 2009). Recognition that the distribution of lodgepole pine in riparian areas is poorly quantified and effects could be larger where lodgepole is abundant; effects also depend on channel type, size, and watershed position. The woody debris budget offers a potential link to existing landscape-scale models that predict impacts (percent basal area killed) under beetle infestation.

Nordin, l.; Maloney, D.; Rex, J.; Krauskopf, P.; Tschaplinski, P.; Hogan, D. 2008. The Bowron River watershed: A landscape level assessment of post-beetle change in stream riparian function. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-22.

Purpose/Study Area Streams and riparian areas in the Bowron River watershed were assessed using RREE (Routine Riparian Effectiveness Evaluation) to determine their level of ecological function 20 to 30 years after accelerated harvest activity. Bowron River watershed was chosen based on past harvesting challenges similar to those associated with the current beetle outbreak. The study is retrospective, allowing a post-logging recovery time of 20 to 30 years. Specific objectives were:

- to review all Bowron River watershed IWAPs (Interior Watershed Assessment Procedures) to quantify the health of the sub-drainages immediately following harvesting;
- to use the RREE to assess current conditions of streams and riparian zones in the most heavily impacted sub-drainages as identified in the IWAPs;
- to assess stream and riparian area recovery in the Bowron River watershed; and
- use results to provide recommendations to guide best management practices that will protect stream and riparian functions in beetle-infested areas.

Methods RREE was used for assessment, a procedure that includes 15 stream and riparian indicators to assess the health and condition of a stream reach. Properly functioning condition, as defined in the *Forest and Range Practices Act,* is the ability of a stream, river, wetland, or lake and its riparian area to:

- withstand normal peak flood events without experiencing accelerated soil loss, channel movement, or bank movement;

- filter runoff; and
- store and safely release water.

These criteria form the backbone of the assessment. Seventy reaches throughout the watershed were evaluated. The sample included two sites in each of the moderate and high-risk sub-basins.

Results Sites in heavily harvested upper-basins had lower evaluation scores than reference sites, mainly because of high failure rates of riparian indicators (e.g., Has the vegetation retained in the Riparian Management Area [RMA] been sufficiently protected from windthrow? Has sufficient vegetation been retained to maintain an adequate root network or LWD supply?). The most heavily impacted sites were within two RMAs logged to the stream bank. Windthrow received a zero failure rate in the harvested group simply because there was no residual timber after riparian harvesting to evaluate. Most failures of the harvested upper-site indicators can be attributed to logging the riparian zone. In many cases the riparian vegetation was completely removed and regeneration was not sufficient to provide the stream with adequate shade or a satisfactory LWD supply. Not only was the riparian plantation too young to yield LWD, but most trees were smaller in diameter than existing accumulations found in the channel, indicating any contribution from the stand would not be of sufficient size to be functional. Future woody debris supply at these reaches is almost certainly going to be scarce for decades, potentially affecting fish habitat, distribution of sediments and coarse particulate organic matter, channel morphology, and nutrient dynamics. The LWD indicator failed > 85% of the time in both upper and lower reaches. Failure was not due to lack of LWD, but too much resulting from harvesting (evidenced by mechanically cut ends). Another frequent indicator failure for harvested upper-sites addressed the question of riparian structure and diversity. A recovery time of less than 30 years after clearcutting did not allow for the regeneration of a riparian forest that was representative of an unmanaged forest as required by the protocol (Tripp et al. 2007). In addition to the direct impacts of tree removal such as lack of shade, excessive LWD (and poor future supply) and insufficient riparian structural diversity, the mechanism of harvest may have contributed to other riparian indicator failures. For example, the use of heavy equipment in the riparian zone likely resulted in an increase of disturbed ground and the propagation of noxious weeds and disturbance-increaser plants. Decades after harvest, even smaller streams did not show recovery of riparian indicators when logged to the stream-bank. Lower-basin harvested sites, representing cumulative effects of the entire sub-basin, scored slightly better overall than upper-basin sites for riparian indicators. Reaches in the lower portion of the sub-basin were generally larger than reaches in the upper-basin and frequently included buffer zones. The average buffer width of lower-basin sites was 23.1 m compared to a 3.3 m average for upper sites. Although the presence of a larger buffer is likely related to lower failure rates of disturbed ground, LWD supply, and riparian vegetation structure compared to upper sites, the harvested lower sites still had a much higher failure rate of these indicators than the reference sites. A regeneration time of 20 to 30 years after clearcutting was insufficient for riparian indicators to recover to pre-harvest conditions. Variation among sites with respect to stream indicators appeared higher within the harvested and reference groups than between them, indicating that harvesting effects have diminished and natural variability is a stronger influence. The within-group variability was explained in part by differences in slope, channel width, coupling (hillslope influence on material transfer to a stream), and soil erodibility.

Gain in Knowledge By evaluating a watershed in an advanced stage of recovery, authors identified impacts to the riparian system and used the information to consider whether compounding forest activities and hydrological response under present forest management practices will incur adverse effects. The evaluation also provides insight into which components recover first. Stream indicators had similar percent failures between reference and harvested sites, indicating potential recovery of stream function since harvest. Conversely, riparian indicators exhibited a much higher failure rate in harvested areas than reference sites. Recovery time for standard riparian indicators exceeded 20–30 years after logging; more time is needed to restore conditions to that of an unmanaged riparian forest. Practices created excessive woody debris in streams and a lack of future supply. Recommendations for salvage logging best management practices are given based on observations of recovery from past harvesting activities and site-specific characteristics.

Tripp, D.B.; Tschaplinski, P.J.; Bird, S.A.; Hogan, D.L. 2007. Field supplement to evaluating the condition of streams and riparian management areas (Routine riparian management effectiveness evaluation). Version 2.0. Forest and Range Evaluation Program, BC Ministry of Forests and BC Ministry of Water, Land and Air Protection, Victoria, BC.

Rex, J.; Krauskopf, P.; Maloney, D.; Tschaplinski, P. 2009. Mountain pine beetle and salvage harvesting: Small stream and riparian zone response in the Sub-Boreal Spruce Zone. BC Ministry of Forests and Range, Forest Science Program, Victoria, BC. Extension Note 90.

Purpose/Study Area The study was conducted in the SBS zone of the Vanderhoof Forest District and addressed two specific questions:

1. What is the riparian stand structure of small streams in beetle-affected areas of the SBS within the Vanderhoof Forest District?
2. How do the beetle infestation (grey-attack stage) and salvage harvesting affect riparian zones and small streams, including shade?

Methods To assess riparian stand structure, basal area studies were completed in unharvested riparian zones of 45 small streams (all identified as pine-leading by VRI). Small stream and riparian zone function was assessed in 2008 for 18 of the 45 steams using RREE (see Nordin et al. [2008] above, this section); 17 had experienced some salvage harvesting, so were subdivided into treatment and control reaches for RREE and shade estimation. RREE protocol requires assessing 15 principal indicators by answering either "yes" (pass) or "no" (fail) questions that guide the user toward a recommendation on the relative health and functionality of a stream and its riparian area. The number of "no" answers in the evaluation determined the overall level of functioning condition of the site: properly functioning condition (0–2 failed indicators); properly functioning, but at low risk (3–4 failed indicators); properly functioning, but at high risk (5–6 failed indicators); or not properly functioning (> 6 failed indicators). Shade was measured following Teti and Pike (2005).

Results The riparian zone within 10 m of the channel bank was mainly composed of spruce regardless of BEC unit. Basal area values were generally lowest near the channel and increased upslope for all study sites. Pine and spruce comprised the largest proportion of total basal area at all study sites, while deciduous trees and balsam fir comprised a smaller proportion; patterns were variable between BEC variants. RREE revealed that control sites generally were properly functioning while harvested sites ranged between properly functioning and not properly functioning. Harvested sites that were properly functioning with a low level of risk generally had buffer widths > 10 m. Control sites had higher shade values than harvested sites.

Gain in Knowledge Affirms that small stream riparian zones in pine-dominated watersheds are spruce dominant. Riparian zones of grey-attack stands were properly functioning according to RREE, whereas harvested areas were properly functioning but with some risk (impairment) or were not properly functioning. Riparian zones of grey-attack stands had higher shade values than harvested sites. Retention within 0 to 5 m was ineffective at keeping functional condition and shade levels similar to those of control areas; higher retention levels were recommended.

Teti, P.A.; Pike, R.G. 2005. Selecting and testing an instrument for surveying stream shade. BC Journal of Ecosystems and Management 6(2):1–16.

Wei, A. 2007b. Long-term evaluation of impacts of wildfire and mountain pine beetle infestation on large woody debris recruitment and transportation processes. FIA–FSP Project Y073127, Final Report.

Purpose/Study Area Study area is IDF and MS near Kelowna. The overall objective is to monitor instream LWD recruitment, and redistribution and transportation processes in forested headwater streams under the influence of wildfire or beetle infestation. The study reports rates of LWD recruitment, redistribution and export, channel morphological features, and litterfall as potential impacts on channel habitat. The design is essentially pairwise: wildfire versus old growth in IDF; beetle infested versus no beetle (control) in MS. This document reports findings from 2005 through 2007; continued work is found in Wei (2009).

Methods Three replicates of each of four site types were measured (wildfire, undisturbed old growth > 120 yrs, beetle salvage, beetle control). Input and export of LWD was measured using "tagged wood and total station shot" method. Shots are photos (consisting of X and Y co-ordinates and an elevation) taken at the two endpoints of the piece at the bankfull points.

Results Annual recruitment rate of LWD pieces was five and eight pieces per 100 m of stream reach in the wildfire sites, about double that in the old-growth (control) sites. Both pine beetle infestation and pine beetle control sites had a yearly recruitment of 2 to 3 pieces per 100 m. Annual output of LWD pieces in the study sites varied greatly, but LWD outputs were higher in old-growth sites compared to the fire sites, and were lower in pine beetle infested streams than in pine beetle control streams. On average, at least 10% of the total instream LWD pieces moved each year in the fire and old-growth streams; highest values were 55% and 35% in fire and old-growth sites, respectively. Mean distances moved of individual LWD pieces did not differ significantly

between fire and old-growth sites, but the longest distance moved by LWD pieces was higher in fire sites. Number of LWD pieces moved in beetle control sites was twice that of the infestation sites. The longest distance a LWD piece moved in infestation sites was about 25 m, compared to 16 m in control sites.

Gain in Knowledge Natural disturbance affected LWD recruitment and transport in forested streams. At the stream reach scale, annual LWD inputs were greater than outputs in wildfire sites, suggesting that fire disturbance caused larger LWD fluxes into streams. In contrast, old-growth streams were found to have a net loss of LWD pieces and thus negative budget values. LWD budget in pine beetle infestation sites was relative stable, while loss exceeded recruitment in pine beetle control streams. This is intended to be a long-term study; further results are found in Wei (2009).

Wei, A. 2009. An experimental approach to assess instream wood (LWD) as an important aquatic habitat indicator within a forest disturbance context. FIA–FSP Project Y091136, Executive Summary.

Purpose/Study Area Study area is IDF and MS near Kelowna. The overall objective is to monitor instream LWD recruitment, redistribution and transportation processes in forested headwater streams under the influence of wildfire and beetle-infestation disturbances. It is a long-term study examining rates of LWD recruitment, redistribution and export, channel morphological features, and litterfall as potential impacts on channel habitat. The design is essentially pairwise: wildfire versus old growth in IDF, MPB versus no MPB (termed reference sites) in the MS.

Methods Three replicates of each of four site types were measured (wildfire, undisturbed old growth > 120 yrs, beetle salvage, beetle control). Input and export of LWD was measured using the "tagged wood and total station shot" method. Potential effects on instream invertebrates were evaluated by vertical litterfall traps, lateral blow-in traps, and organic flux netting; benthic macro-invertebrate were sampled by haphazard rock collection.

Results Annual rates of LWD recruitment and transport varied greatly with the site types and years: 7.0 ± 1.6 pieces (mean ± SD) or 1.03 ± 0.15 m3 of LWD volume per 100-m stream reach recruited annually to the burned sites; significantly higher than in undisturbed old-growth forest sites (3.0 ± 1.3 pieces and 0.38 ± 0.22 m3, respectively). Beetle-attacked sites were similar: 2.6 ± 0.8 pieces per 100-m stream reach in both infested and reference sites. Burned sites annually gained about one to five pieces (0.29–0.92 m^2 of LWD volume) per 100-m stream reach during the 4-year monitoring period. Values for undisturbed sites (old growth) were slightly lower: beetle-attacked sites added 0 to 2.7 pieces per 100-m stream reach per year, while reference sites lost 0.3–2.7 pieces per 100-m stream reach. About 13–48%, 3–66%, 12–18%, and 13–28% of the total LWD pieces were annually redistributed in old growth, burned, beetle-attacked, and reference sites, respectively, with the average transport distances of 13–15 m, 17–22 m, 7–20 m, and 9–25 m in the four site types. Specifically, 20–57%, 22–88%, 8–21%, and 11–33% of the first-year tagged LWD pieces have been exported from the studied reaches in old growth, burned, beetle-attacked, and reference sites, respectively. Macro-invertebrate sampling was unsatisfactory.

Gain in Knowledge Provides the first stream reach scale data of recruitment rates of LWD pieces in interior British Columbia forested watersheds. Wildfire and beetle infestation had large impacts on dynamics of LWD, channel morphology, and input of litterfall. They also changed stream channel morphological characteristics (primarily pool depth). Beetle infestation increased needle mass and reproductive materials. Export rates of LWD pieces were significantly less in beetle-attacked sites than in reference sites. Note: on the basis of review by Huggard (2008a,b) this study should extend at least 10 years to incorporate 50% of the natural fall-down of beetle-killed snags.

Stream Temperature and Fish

Hinch, S. 2008. Long-term stream habitat and rainbow trout responses to alternative riparian management in north-central British Columbia. FIA–FSP Project Y081216, Executive summary.

Purpose/Study Area The study exploits previous studies to evaluate longer-term consequences. Earlier studies had included experimental removal of all commercial timber within the riparian reserve zones while retaining non-commercial coniferous trees and deciduous vegetation (in violation the Forest Practices Code of the day, but allowed under the current FRPA and which mimic riparian salvage logging undertaken due to beetle infestations). It addressed six questions:

1. Have summer stream temperatures and canopy cover levels recovered or exceeded pre-logging conditions?
2. Does the model of Mellina et al. (2002; see Mellina below) accurately predict temperature changes for resulting canopy cover?
3. Are rainbow trout densities, biomass, distribution, and condition affected by logging as theoretical models suggest?

4. Have stream habitat features begun to deteriorate as models suggest?
5. Are interannual changes in habitat and fish responses related more to interannual environmental fluctuations and to the natural differences inherent among the streams, as short-term data indicate, than to impacts of logging?
6. Are longer-term post-logging habitat and trout responses less severe in lake-headed streams than headwater streams as shorter term data indicated?

Study area was three small lake-headed S3 streams located within the SBS zone of north-central BC, previously evaluated for stream temperature (Mellina below).

Methods Summer stream temperatures and canopy cover levels were assessed using established statistical techniques and stream temperature and canopy cover monitoring protocols (Mellina et al. 2002). Number and dimensions (length, width, and depth) of all pools within the study boundaries were measured. Stream-resident rainbow trout densities, standing crop biomass, distribution, and condition were assessed through streamwide electroshocking surveys conducted within the study boundaries of all three streams during summertime low flows.

Results Despite reductions of ~ 50% in canopy cover following logging, summertime stream temperature increases were relatively modest in the short-term (averaging < 1.5°C with respect to daily mean, maximum, minimum, fluctuations, and downstream cooling); the greatest increases (averaging 2–5°C) were observed 6 to 10 years after logging operations, when canopies had recovered to ~ 75 to 99% of pre-logging levels. This increase is attributed to a product of warm summers and shift in riparian cover from tall, coniferous canopy prior to logging to thick, low, deciduous undergrowth. Post-logging summer suspended sediment levels remained low (< 1 NTU), and average summer dissolved oxygen (DO) concentrations in all three streams remained above 8 mg/L (salmonid threshold). Pool configuration did not appear affected by logging treatments. The rainbow trout population age structures remained relatively stable during the pre- and post-logging periods. Although reductions in juvenile (ages 1–4) density and biomass were observed in all three streams during the same period, the greatest reductions generally occurred in the two treatment streams. Trout distributions were more frequently aggregated in the treatment than in control streams. Condition indices for young of the year (as a surrogate for growth) were generally equal for all three streams in the 5 years of monitoring. Overall, lake-headed streams' temperature and DO responses to streamside clearcut logging differed from those of headwater streams. Small, lake-headed streams may be able to support a more aggressive level of streamside harvesting involving the removal of most commercial timber within the riparian zone while retaining deciduous vegetation and non-commercial as well as some commercial trees. Results suggest that the short- to longer-term (1–10 years) effects of streamside logging around these treatment streams were associated with increases in young-of-the-year (but not juvenile) density and biomass levels. However, the similarity in the temporal patterns of stream habitat and rainbow trout response variables between the treatment and control streams suggest that the observed short, medium, and longer-term post-logging changes may be related more to interannual environmental fluctuations and to the natural differences inherent among the streams than to these logging treatments.

Gain in Knowledge Provides the first long-term, before and after logging, fish–forestry case study (> 10 years, the equivalent to three full generations of rainbow trout) in temperate, interior regions in BC. This is significant because many post-logging effects to streams are not evident until 10+ years after logging. There were no pronounced effects on rainbow trout and effects observed appear to be as much a consequence of natural variation as of harvest. However, the sample streams were lake-headed so tend to be warmer and, among salmonids, rainbow trout tolerate reasonably warm waters. However, Maloney (2004) obtained similar results in headwater streams. Temperature increases reported could be detrimental to species, such as bull trout, that require cooler water.

Hinch, S.; Mellina, E. 2008. Stream habitat and bull trout *(Salvelinus confluentus)* responses to MPB riparian salvage harvesting in north-central British Columbia. FIA–FSP Project Y091046.

Purpose/Study Area Bull trout have a different life history and thermal requirements than do rainbow trout; the former are cold-water (< 12°C) adapted and are fall spawners, whereas the latter can tolerate warmer temperatures (15–17°C) and are spring spawners. This project sought to address five questions:

1. Do beetle-affected and logged streams have different summertime temperatures?
2. How do temperatures in logged streams compare to the optimal and lethal temperatures for bull trout?
3. Do bull trout densities, standing crop biomass, distribution, and condition differ between treatment and forested streams?
4. Do stream habitat features differ between the treatment and forested streams, and do any such differences translate into changes in bull trout abundance, biomass, and condition?
5. Do post-logging responses differ between bull trout and rainbow trout?

The proposed study area was the Northern Interior Forest Region.

Methods Most proposed methods are immaterial because after reconnaissance the researchers recommended the project be terminated. Results reported here are based on detailed, map-based searches followed by groundtruthing for suitable study streams. BCMoE, Canfor, and consulting firms provided guidance in selecting candidate streams.

Results Of candidate streams in watersheds identified as containing bull trout, none merited sampling after groundtruthing because of the low likelihood of bull trout presence. A total of 56 streams were sampled within the Anzac, Herrick, and Bowron watersheds, of which 34 had riparian zones that were logged. Bull trout were captured in only five streams (all forested), with densities ranging from 2 to 14/100 m; rainbow trout was the only species captured in 12 streams (4 forested, 1 recently logged, 7 older logged); sculpins were the only fish captured in three streams (2 forested, 1 older logged); both rainbow trout and sculpins were captured in nine streams (4 forested, 1 recently logged, 4 older logged). Moreover, riparian zones of the sampled streams were largely dominated by spruce and therefore unaffected by the beetle. The design could not be implemented; researchers recommended the project be terminated.

Gain in Knowledge Reconnaissance activities in watersheds identified as containing bull trout found few streams historically or recently logged to stream banks. The blue-listed status of bull trout may have helped ensure streams containing the fish either remained forested or had substantial buffer strips along their riparian zones to protect fish habitat, even in areas logged over 30 years ago. Canfor (the major company in the area) typically follows riparian guidelines. The same level of protection did not seem to have been afforded to streams with rainbow trout: the species was captured in 13 of the logged streams sampled. A competing hypothesis—from that of bull-trout-bearing streams being protected from logging activities—is that these streams indeed contained bull trout prior to logging, but that streamside timber harvesting increased temperatures, which favored rainbow trout to the exclusion of bull trout. That hypothesis cannot be addressed with existing data.

Maloney, D. 2004. The effects of riparian harvesting on fish habitat and ecology of small headwater streams. FIA–FSP Project R04-032, Year-end Report.

Purpose/Study Area The project evaluated consequences of policy for S4 streams in the Prince George Forest District. It reports on one aspect: the degree to which 50 to 70% of the natural levels of shading were maintained (light intensity reaching the stream surface and forest floor).

Methods The project used a "Before-after-control-impact paired (BACI-P)" design on nine small headwater streams in three geographically distinct forest types (Tagai Lake, Chuchinka River, and Bowron River). The report notes that "A complete description of the sampling methodology, the location of each sampling site, and a summary of the data collected in the fall of 2001 has been prepared and is available from P. Beaudry and Associates." The 2003–04 water temperature data analysis involved comparing the post-harvest treatment data to the pre harvest treatment data.

Results Logging treatments reduced canopy cover by 39 to 49%. Small headwater streams in the region are generally cold. Riparian harvesting treatments slightly increased temperatures: daily mean, maximum, and minimum temperatures and daily fluctuations, were < 1.5°C warmer, compared to increases of ~ 5 to 7°C reported in predominantly coastal literature. Researchers conclude that the small temperature changes observed in the streams are not likely to be detrimental to resident rainbow trout. Note, DFO and Beaudry and Associates apparently have different portions of results (these were not retrieved).

Gain in Knowledge The model of Mellina et al. (2002) predicts stream temperature increases from canopy/shade removal reasonably accurately. Increases do not appear large enough to affect rainbow trout. These findings are similar to those of Hinch (2008) for lake-headed streams.

Mellina, E. 2006. Stream temperature responses to clearcut logging in the central interior of British Columbia: Test of the predictive model developed by Mellina et al. (2002). Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2006-08.

Purpose/Study Area Mellina et al. (2002) developed a model to predict downstream temperature trends in small headwater and lake-headed streams using easily measured predictors. This study evaluated the model's generality and predictive capability across 20 lake-headed and headwater streams in north-central BC (SBS zone).

Methods Summertime stream temperature and canopy cover data collected from 20 small lake-headed and headwater streams in north-central BC were compared to predictions of the model developed by Mellina et al. (2002).

Results Lake-headed streams were initially warmer at their source than were headwater streams. Downstream cooling was widespread among lake-headed streams, and downstream warming was prevalent in headwater streams, regardless of whether the riparian zones were harvested. Data suggest that temperature increases following streamside timber harvesting around lake-headed streams were smaller than headwater streams and that increases were likely mitigated by a combination of warm outlet temperatures from lakes and cold groundwater inputs. The model appears broadly accurate (deviations of 0.02–0.96°C) for average daily downstream cooling or warming over complete summertime data and somewhat less so for restricted summer periods (deviations of 0.01–2.53°C).

Gain in Knowledge Post-logging reduction in streamside canopy cover produced minor changes in downstream daily mean, maximum, and minimum temperatures, as well as daily fluctuations and cooling. Summertime downstream daily mean temperatures rose by an average of 0.05°C, daily maximum temperatures by 0.4°C, and daily fluctuations by 0.7°C. Summertime daily minimum temperatures and downstream cooling decreased by an average of 0.3°C and 0.1°C, respectively. At upslope sites, lake-headed streams were naturally warmer than headwater streams. Most headwater streams (8 out of 9 forested, and 2 out of 3 logged) had downstream warming, whereas most lake-headed streams (all the forested, and 3 out of 4 logged) had downstream cooling. At downslope sites affected by logging, logged headwater and lake-headed streams were generally warmer and had greater daily fluctuations than their forested counterparts. Canopy cover was reduced by an average of ~ 31% in logged versus forested lake-headed streams, compared to reductions of only ~ 9% in logged versus forested headwater streams. Potential effects on rainbow trout are equivocal, but do not appear large (see Hinch 2008).

Mellina, E.; Moore, R.D.; Hinch, S.G.; Macdonald, J.S.; Pearson, G. 2002. Stream temperature responses to clearcut logging in British Columbia: The moderating influences of groundwater and headwater lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1886–1900.

8.2.5 Climate Change

Aukema, B.H. 2009. Bark beetle response to climate change: A landscape-level stochastic risk model for British Columbia. FIA–FSP Project Y081277, Year-end Report. (the final year is outstanding)

Purpose/Study Area The project develops a spatiotemporal, statistical climate change model specifically for mountain pine beetle. Only the input data are area-specific; underlying relations are more widely based. The objective is to predict estimates of outbreak probability on annual bases, with standard errors, at clearly defined scales.

Methods Aerial survey data of tree mortality due to mountain pine beetle were used in a GIS, optimized by likelihood techniques to permit selection of the best model. A spatiotemporal, autologistic regression model was used to examine the likelihood of outbreak in a given grid cell, given the arrangements of local populations of outbreaking insects in space and time.

Results A projection framework specific to the beetle has been created and proof of concept applied to the Chilcotin Plateau outbreak (1972–96).

Gain in Knowledge Both winter temperatures (lethal to overwintering larvae) and summer temperatures (critical to brood maturation and dispersal) drove the beetle's propagation and spread. Trends could be quantified statistically by considering landscape trends of dispersal at large scales (km) and reproduction through time (lags of up to 2 years). Tests of ability to project are not yet reported.

Carroll, A.L.; Taylor, S.W.; Régnière, J.; Safranyik, L. 2004. Effects of climate change on range expansion by the mountain pine beetle in British Columbia. Pages 223–232 *in* T.L. Shore, J.E. Brooks, and J.E. Stone, eds. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30–31, 2003, Kelowna, British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Information Report BC-X-399.

Purpose/Study Area The report evaluates the degree to which expansion of the beetle in British Columbia is a product of climate. Detailed analyses of climate are restricted to BC.

Methods Historic weather records were used to produce maps of the distribution of past climatically suitable habitats for the beetle in British Columbia. Overlays of annual beetle occurrence on these maps were used to determine if the current expansion of beetle was associated with changing climate.

Results Climate maps closely delineate areas currently experiencing epidemic populations; there has been a concomitant increase in mature lodgepole pine.

Gain in Knowledge Continued warming in western North America will let the beetle expand its range northward, eastward, and toward higher elevations. Expansion as global warming continues will provide it a small continual supply of mature pine, thereby keeping populations greater than normal for decades.

Carroll, A.L.; Régnière, J.; Logan, J.A.; Taylor, S.W.; Bentz, B.J.; Powell, J.A. 2006. Impacts of climate change on range expansion by the mountain pine beetle. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC.Mountain Pine Beetle Working Paper 2006-14.

Purpose/Study Area The report extends analyses of Carroll et al. (2004) by projecting impacts of climate change. Analyses are Canada-wide.

Methods Same as Carroll et al. (2004), plus climate projections using the CGCM1 global circulation model and a conservative forcing scenario (equivalent to a doubling of CO2 relative to the 1980s by about 2050). Predicted weather conditions were combined with the climatic suitability model to examine the distribution of benign habitats from 1981–2010 to 2041–70 for all of Canada.

Results The area of climatically suitable habitats is anticipated to continue to increase within the beetle's historic range. Moreover, much of the boreal forest will soon become climatically available to the beetle. Because jack pine is a viable host and a major component of the boreal forest, the beetle's continued eastward expansion is probable.

Gain in Knowledge Even restrictive predictions of the distribution of climatically suitable habitats suggest that much of the boreal forest will be available to mountain pine beetle in the near future. Although the potential rate of increase of beetle populations in jack pine and the abundance and distribution of susceptible stands within the boreal forest are currently unknown, the beetle's continued eastward expansion seems probable.

8.3 Wildlife Responses

Only terrestrial vertebrates are treated here. Responses of fish are reviewed under stream temperature and elsewhere in hydrology (section 8.2.4).

8.3.1 Birds

Bonnot, T.W.; Rumble, M.A.; Millspaugh, J.J. 2008. Nest success of black-backed woodpeckers in forests with mountain pine beetle outbreaks in the Black Hills, South Dakota. The Condor 110(3):450–457.

Bonnot, T.W. 2006. Nesting ecology of black-backed woodpeckers in mountain pine beetle infestations in the Black Hills, South Dakota. M.Sc. Thesis, University of Missouri, Columbia, MO.

Purpose/Study Area This study investigated nest survival and habitat use by black-backed woodpecker of forests infested by mountain pine beetle in the Black Hills, South Dakota.

Method: Beetle-infested study sites were identified using remote sensing imagery and plane flights. Sites were searched for nests and call playback was used to find individuals. Nests were monitored every 2 days to develop a nest survival model. Habitat characteristics were recorded at nest sites.

Results Forty-three nests were monitored. Nest survival rates were similar to those found in burnt forests (> 44%). There was little apparent relation to indices of beetle abundance, suggesting that nest site selection was more important to nest survival than food availability. More than half the nests were in salvaged areas; 65% of these nests were successful. Dead pines provided the majority of nest trees (76%).

Gain in Knowledge Forests infested with beetles appeared to support black-backed woodpecker as well as did burnt forests. Results contradict other studies by indicating that nest site selection is more important for nest survival than food increase from infected pines. Dead pines provide both food and nesting trees for black-backed woodpecker. Moderate salvage logging had little effect on nest survival.

Chan-McLeod, A. 2007. Integrating silvicultural control of mountain pine beetle with wildlife and sustainable forest management objectives. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2007-05.

Purpose/Study Area See annotation in section 8.1.2.

Methods The same eight treatments were employed as for windthrow and structure (section 8.1.2). One hundred and eighty one bird sampling stations were established in 25 forest stands and cutblocks; three replicates for each treatment (except controls). Stratified random sampling was used to layout bird stations in each stand. Two strata were defined for partial retention cutblocks: a) residual patches and b) cut over matrix, which may or may not contain dispersed trees. Samples were 60-m radius plots on 200-m gridlines.

Results There were 4320 birds detected: 63 species in 2004; and 67 in 2005. Dark-eyed junco comprised 20% of detections. The most consistent and pronounced treatment effects were between controls and all other harvest treatments. In 2005, four species: brown creeper, Cassin's vireo, golden-crowned kinglet, and three-toed woodpecker were abundant in beetle-infested control plots but present in only two or three of the seven harvest treatments. Other species with significant treatment effects included Hammond's flycatcher, red-breasted nuthatch, and Swainson's thrush—all were more abundant in controls than treatments. Red eyed vireo, western tanager, and winter wren also seemed to prefer the controls, but low statistical power prohibited significant effects. Amount of retention in the treatments had more effect than cutblock size. Birds usually found in mature forest used treatments with greater retention more than treatments with less retention regardless of cutblock size.

Gain in Knowledge Treatments with retention were preferred over less retention by birds usually associated with mature forest, but use of controls was higher than use of any of the treatments. Results apply to recently harvested blocks as fall down will reduce retention over time.

Chan-McLeod, A.; Zhu, X.; Klinkenberg, B. 2008. Factors affecting the ecological legacy of unsalvaged post-mountain pine beetle stands. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-19.

Purpose/Study Area This study documented the short-term ecological legacy of unsalvaged post-beetle forest stands in the Prince George and Vanderhoof Forest Regions.

Methods Bird survey data (116 bird circular point count stations with 60-m radii at 25 mature forest sites) and stand structure measures were collected at the study sites. Researchers selected mature, post-beetle forest stands that would provide as wide a range as possible in the values of factors addressed, specifically, the neighbourhood composition, the type and amount of residual green component in the infested stand, stand size, and time since infestation.

Results In the short term (< 5 years) following beetle attack, non-beetle factors such as the pre-existing stand structure, pre-existing site features (i.e., presence of a riparian area), and interannual variations resulting most likely from climate and other non-mountain pine beetle factors, were as important or more important than the beetle in dictating bird abundance. However, the beetle had measurable effects on avian abundance, with about 64% of bird species and 62% of avian community variables responding to the level of beetle infestation within the stand. Kind of effect reflected the natural history of the bird. Species that declined with increasing levels of infestation were generally foliage gleaners (e.g., Swainsons' thrush, warbling vireo, and western tanager) responding to the rapid deterioration in the foliage. In contrast, cavity nesters increased with increased intensity of beetle attack, probably in response to the increased supply of suitable nest sites in dead and dying trees. Paradoxically, the golden-crowned kinglet, which is a foliage-gleaner and commonly found in closed-canopy coniferous forests, also increased with levels of beetle infestation. Although golden-crowned kinglets feed primarily on insects, they may be capitalizing on the easy access to insects trapped in pine sap during the beetle epidemic.

Gain in Knowledge The beetle's relatively low impact on avian communities up to 5 years post-attack indicates that there is no ecological incentive for immediate salvage logging. Although time since death of a tree was not a major determinant of abundance for most species during the first few years post-attack, this likely will change as the stand continues to break up. After 8 to 10 years, as the stand opens significantly from falldown of snags, beneficial effects will accrue to species that thrive in open conditions, but negative effects of the beetle on wildlife species that depend on the forest for cover will become more apparent. When this happens, there may be a ripple effect in the food chain, with predators of affected species also experiencing declines.

Drever, M.C.; Aitken, K.E.H.; Norris, A.R.; Martin, K. 2008. Woodpeckers as reliable indicators of bird richness, forest health and harvest. Biological Conservation 141:624–634.

Purpose/Study Area This study used data from 23 sites located north of Williams Lake to determine if there was a correlation between woodpeckers and other forest birds at the stand level. It investigated the similarity of species richness and habitat use between the two species groups at the stand level and among a diverse range of forest types, including beetle-infested forests.

Method: Bird communities were surveyed (1997–2006) in uncut forests (mixed and coniferous), stands with 15 to 30% removal (either commercial removal or beetle-killed) and clearcuts with reserves. Surveys used bird point counts and playbacks to estimate species richness; vegetation and habitat variables were recorded. Bird correlation was determined by a mixed-effect modelling approach.

Results Bird richness correlated positively to woodpecker richness (woodpeckers comprised about 8% of the species in analysis). Variations of bird and woodpecker richness were consistent at the stand and landscape levels. Both groups were associated with similar habitat attributes (e.g., number of tree species) and responded similarly to forest harvest. Bird and woodpecker richness were lowest in uncut forests, followed by partial harvest and clearcuts with reserves. Richness differed for one variable: density of red-attacked pines. Woodpecker richness correlated positively to density of red-attacked pines while overall bird richness was negatively correlated.

Gain in Knowledge There is evidence of broad correlation between species richness of woodpeckers and richness of other forest birds at the stand and landscape levels and throughout harvest patterns. However, during insect outbreaks, responses of woodpeckers and of other bird communities differ and the correlation no longer holds. This is likely because some species are foliage gleaners while others pursue wood-boring insects.

Martin, K.; Norris, A.; Drever, M. 2006. Effects of bark beetle outbreaks on avian biodiversity in the British Columbia interior: Implications for critical habitat management. BC Journal of Ecosystems and Management 7(3):10–24.

Davidson, P.; Easton, W.; Martin, K. 2007. Beetlemania in British Columbia. Bird Watch Canada 39:8–11. FIA–FSP Project M08512.

Purpose/Study Area These papers summarize field observations on cavity nesters and their habitat throughout a beetle outbreak and salvage logging of these forests. Study area as for Drever et al. (2008) above.

Method: Data collection began before the outbreak and spanned from 1995 to 2005. Vegetation and characteristics of trees and forest stands were recorded each year, and for more than 10 000 individual trees. Nests of birds and squirrels were found by systematic searches. Population densities were assessed using point-counts and playback techniques.

Results The beetle infestation occurred rapidly and in patches throughout the landscape. In 1995, 90% of the trees were healthy and 2% of conifer trees were attacked; in 2005, only 45% of the trees were healthy with 40% being affected by beetles. The beetle attack was distributed across the sampling sites with a high degree of variability (5–82% tree mortality). Bird species richness remained the same through the outbreak but species abundance varied. Some species responded to increased food supplies. abundance of resident cavity-nesting species increased, except for black-capped chickadee and pileated woodpecker. Populations of northern flicker, red-naped sapsucker, olive-sided flycatcher, western wood-pewee, and yellow-rumped warbler decreased. Nesting density of red-breasted nuthatches increased up to 50% with the outbreak, but returned to pre-outbreak levels in 2005.

Appendix 1 provides a list of the species observed and indicates those that forage on the beetle.

Gain in Knowledge Heterogeneity in spatial and temporal distribution of the beetle attack likely helped maintain species richness. Not all species of birds are positively affected by insect outbreaks depending on specific limiting factors (e.g., nest trees, food). Mountain chickadees apparently depended on beetle abundance for food and on woodpecker density for nest sites. The beetle's positive effect is ephemeral; evidence of 'boom and bust' was documented for red-breasted nuthatch and mountain chickadee.

Norris, A.R. 2007. The responses of two cavity-nesting species to changes in habitat conditions and nest web community dynamics in Interior British Columbia. MSc thesis. University of British Columbia, Vancouver, BC. FIA–FSP Project M085126.

Norris, A.R.; Martin, K. 2008. Mountain pine beetle presence affects nest patch choice of red-breasted nuthatches. Journal of Wildlife Management 72(3):733–737.

Purpose/Study Area The study was conducted in the same area near Williams Lake as the two previous studies (namely, Drever et al. 2008 and Martin et al. 2006). The purpose was to investigate patterns of nest patch selection by red-breasted nuthatches in forests affected by beetle outbreaks. Forest patches investigated were 0.1 to 5 ha, and were isolated by a matrix of grasslands, ponds, and wetlands.

Method: From 1995 to 2005, systematic searches for active nests were conducted. Data on vegetation, tree population, and density of beetle-infected pines were collected each year. Generalized linear mixed-effects models were used to compare nest patch selection between pre- and post-beetle attack. Influences of aspen trees, suitable nest trees, and beetle-infested trees on nuthatch nest patch selection were evaluated.

Results Selection criteria of nuthatches were different pre- and post-outbreak. Pre-outbreak, red-breasted nuthatches selected nest patches with higher mean density of aspen trees and aspen nest trees, as expected. During outbreak years, they selected nest patches with higher densities of beetle-infested tree than available and fewer aspen trees. The nuthatch population doubled and clutch sizes increased by 30% with the beetle outbreak (see Norris and Martin 2008).

Gain in Knowledge Forest insect outbreaks influenced nest patch selection by red-breasted nuthatches. Nest patch selection post-outbreak tended to be directed towards food supply rather than nest tree availability. Beetle outbreaks provide greater food supplies (larvae under bark in winter; adult beetles in summer), and likely increase survival and population of nuthatches. However, the increase in food supply was ephemeral and declined as pines died.

Stone, W.E. 1995. The impact of a mountain pine beetle epidemic on wildlife habitat and communities in post-epidemic stands of lodgepole pine forests in northern Utah. PhD thesis. Utah State University, Logan, UT.

Purpose/Study Area This study was conducted outside the province, but is relevant. It investigated the effect of a mountain pine beetle epidemic 3 to 8 years post-outbreak on canopy, understorey, birds, mammals, and insects in northern Utah.

Method: Sampling sites were chosen in stands with tree mortality ranging from 14% to 95%. Birds were surveyed with point counts, small mammals by live trapping, ungulates by using fecal pellet surveys, and insects with sticky traps and sweep netting.

Results Abundance and diversity of wildlife species was generally enhanced by the outbreak, except in sites with the most tree mortality. Species that forage on conifer seeds or glean conifer foliage (red squirrel, pine grosbeak, Audubon's warbler) responded negatively to the outbreak, as did the northern goshawk (perhaps due to the decline in squirrels). As canopy foliage disappeared, understorey gained in diversity and structural heterogeneity, enhancing mammal and bird species associated with understorey. Bird and small mammal richness was highest in stands with moderate (25–75%) tree mortality compared to those with low (< 25%) or high (> 75%) tree mortality. Ungulate fecal pellet counts correlated with percent tree mortality. Insect abundance increased linearly with tree mortality and insect richness was highest in stands experiencing moderate to severe mortality.

Gain in Knowledge Results indicate that beetle attack has a substantial effect on forest-dwelling wildlife. Species richness is highest when disturbance is intermediate in frequency or intensity. At highest tree mortality levels, species are negatively affected.

8.3.2 Mammals

(FSP) Forest Science Program. 2008. Enhancing the resilience of the Tweedsmuir–Entiako caribou to the current mountain pine beetle outbreak. FIA–FSP Project Y081259, Executive Summary. (complements Cichowski [2009] below)

Purpose/Study Area This modelling project started in 2007. Its purpose was to evaluate current habitat of the Tweedsmuir–Entiako caribou herd in central British Columbia, assess how it was affected by the beetle outbreak, and determine which forest management strategies could enhance herd resilience.

Methods The model is intended to include data on caribou location and habitat/lichen composition from Cichowski and MacLean (2005), and data from a workshop with experts and literature review. Additional data will include topography, soil

moisture, forest cover, historical data, and landsat imagery. Models on predator–prey dynamics and landscape projection (including forest management processes, mountain pine beetle dynamics, stand dynamics) will be integrated.

Results In year 1 data were collected, workshops conducted, and literature reviewed. Model runs and scenarios will be produced the 2nd year. Subsequent reports (annotation following) report no updates to models.

Gain in Knowledge Gaps and uncertainty were identified (incompletely); e.g., length of time for dead, beetle-infected trees to fall; shift in vegetation/lichen composition; habitat recovery rate; changes in predator–prey dynamics including other ungulate population dynamics. Note: some of these gaps have been filled or partly addressed (e.g., snag fall rates and shifts in vegetation composition).

> Cichowski, D.; MacLean, N. 2005. Tweedsmuir–Entiako caribou population: Technical background information summary. Prepared for BC Ministry of Environment, Smithers, BC.

Cichowski, D.B. 2009. Tweedsmuir–Entiako caribou project: Effects of a mountain pine beetle epidemic on northern caribou habitat use. FIA–FSP Project Y091159. Annual reports 2006/07, 2007/08, and 2008/09.

Purpose/Study Area This study began in 2005 in the North Tweedsmuir Park (summer range), Entiako, and east Ootsa (winter range). The purpose was to follow caribou migrations at the landscape and stand levels, and to evaluate habitat use and forage site selection during the grey phase of the beetle outbreak.

Methods Adult female caribou were tagged with radio collars (GPS and VHF transmitters) and radio-telemetry flights were used to locate animals. Snow condition was recorded randomly, and at terrestrial lichen feeding sites; caribou tracks and adult mortality were recorded; population surveys by helicopter in the fall and winter determined calf survival rates.

Results Changes in snow conditions due to grey-attack affected caribou foraging on terrestrial lichens less than weather conditions did. Seasonal movements and habitat use resembled those prior to beetle outbreak. During early stages of the outbreak, caribou continued to select mature pine habitat with abundant terrestrial lichens during winter. Snowpack as much as 93 cm did not stop caribou from digging craters in open pine habitat. Greater snow accumulation in 2006–07 confined the caribou on their winter range longer than usual. Calf recruitment rate was low to moderate.

Gain in Knowledge Migration pattern and foraging habits of caribou did not change during early stages of the beetle epidemic.

Goward, T.; Ovenden, G.; Arsenault, A. 2008. Mountain pine beetle as an agent of enhanced hair lichen biomass, with implications for the winter ecology of mountain caribou. FIA–FSP Project M085281b, Final Technical Report.

Purpose/Study Area The study tested a model for the distribution of *Bryoria* species (hair lichens) using field data collected in southern Clearwater Valley, south central British Columbia. The model is meant to predict loading of hair lichens in forests affected by mountain pine beetle outbreaks.

Method: The model is based on the assumption that *Bryoria* species are closely associated with macroclimate. Elevation determined macroclimate classes for data collection and construction of the model. Data were collected at elevations between 600 and 1600 m. A detailed methodology was developed to quantify the vertical distribution of hair lichen in canopy of 165 permanent plot trees. Branch characteristics, loadings of hair lichens, macroclimate variables, ground cover, and neighboring vascular vegetation were recorded.

Results Results are intended to be submitted to a peer-reviewed journal. The authors consider the resulting model hypothetical, although field data showed it to be a useful predictor tool of Bryoria species distribution in ungulate winter ranges. The study is intended to continue until 2012 and data are still being gathered (T. Goward, UBC Herbarium, pers. comm., 2010).

Gain in Knowledge It appears possible to quantify and scale up small-scale hair lichen loading on pine tree branches for broader-scale models or planning.

Lewis, D. 2008. Quantitative synthesis of wildlife habitat relationships to stand-level green tree retention following harvest and natural disturbance in lodgepole-pine dominated (NDT3) habitats. FSP Project S084014, Executive Summary. (see annotation in section 8.1.3)

McNay, R.S.; Sulyma, R.; Voller, J.; Brumovsky, V. 2008. Potential implications of beetle-related timber salvage on the integrity of caribou winter range. FIA–FSP Project M085236, Poster.

Purpose/Study Area This poster reports a model based on conditions in the Fort St. James area of north-central BC and plans to predict outbreak and salvage logging impacts on woodland caribou habitat.

Method: Four timber harvest scenarios with projections over 80 years:

1. a base case in pre-beetle landscape with 50% of UWRS reserved;
2. emphasis on pine salvage with modest limits on new road construction;
3. same as (2) but with fewer constraints on roads and salvage in UWRs was not constrained; and
4. same as (3) but with an 40% increase in AAC during the salvage period.

Results Projections suggest salvage logging need not degrade caribou winter range in the region. During salvage, increases to harvest levels showed limited amounts of caribou habitat affected; during the post-salvage period, maximizing habitat values for caribou had relatively low impacts on timber supply. Impact of predation is expected to increase with roads and early seral stands that are associated with salvage logging.

Gain in Knowledge The tradeoffs between maintaining AAC and caribou winter range do not necessarily conflict.

Munro, R.; McLellan, B.; Apps, C. 2008. Implications of forest management in response to the 1970's mountain pine beetle infestations on grizzly bears and moose in the Flathead Drainage. FIA–FSP M086037.

Purpose/Study Area This retrospective study was conducted in the Flathead Valley, southeastern British Columbia, an area salvage logged following a beetle outbreak in the 1970s. It investigated population trends of grizzly bears during a 30-year period following salvage logging and habitat selection by bear and moose in these landscapes post-outbreak.

Methods Locations from 133 grizzly bears tagged with radio collars (14 with GPS collars) were recorded from 1978 to 1992. Population data were collected and used to evaluate mortality, reproductive, and survival rates. An index of bear density across the landscape was developed using DNA census. The landscape was divided into three treatments zones: the watershed zone, the lodgepole pine-leading forests stands, and an area with small pockets of lodgepole pines. Bear DNA census was used to evaluate current bear use of the three treatment zones. Influence of immature forests and road density on habitat selection by grizzly bear was evaluated across spatial scales using locations from bears with GPS collars, air photos, forest cover maps and mortality data. Habitat selection by grizzly bears in relation to stand attributes and food availability was investigated in three types of stands: 5- to 15-year-old clearcuts, 25–35-year-old, salvage-logged areas, and 60-year-old lodgepole pine stands. In these same stands, winter microsite habitat selection by moose was investigated using telemetry data for 1 year.

Results There was no significant difference in bear detection among the three treatment zones. Influence of immature forests and road density on bear habitat selection varied across spatial scales. On average, female grizzly bears in 2005 spent 30% of their time in either pine-dominated stands or regenerating cutblocks. Grizzly bears were significantly more likely to die from human intervention in landscapes with high road density and access, and with young forest stands. The grizzly bear population increased during the first two decades, when salvage logging was very active, but reproductive and survival rates showed a dramatic decline in the third decade. This decline was likely due to a decline in carrying capacity. In the third decade, ungulate populations decreased dramatically due to liberal hunting regulations and wolf recolonization. Production of huckleberry, a major food source during 2 to 3 months of the year, also decreased as canopy closed. Bears avoided regenerating cutblocks and young salvaged-logged regenerating stands due to lack of food. Results on moose habitat selection were not conclusive.

Gain in Knowledge Salvage logging due to the beetle outbreak in the 1970s did not appear to cause the decline in reproduction and survival rates of grizzly bear cubs. Decline of food sources such as ungulates and huckleberries were more likely responsible. Although salvage logging did not directly affect bear population trend, it may have had indirect impacts. Just like cutblocks, regenerating salvaged stands become less favored by grizzly bears due to lack of food as canopy closes. More importantly, if additional road and access is created during salvage logging, chances of bear mortality due to human intervention is likely increased.

Seip, D.; Jones, E. 2009. Response of woodland caribou to partial retention logging of winter ranges attacked by mountain pine beetle. FIA–FSP Project Y091010.

Purpose/Study Area The study began in 2006 in the Southern Mountains National Ecological area. About half the ungulate winter range affected by a beetle outbreak was to be salvaged logged. The project monitors changes in habitat use of the Kennedy Siding caribou herd and responses of vegetation and snow in areas with beetle outbreaks and salvage logging.

Methods Six caribou were tagged with GPS radio collars to monitor habitat use at the stand level. Foraging behavior was assessed by following tracks in snow and evaluating foraging sites in pine forest and clearcut/salvaged blocks. Permanent plots were established to sample vegetation, lichen, and snow conditions in salvaged-logged areas, old clearcuts, and pine forests attacked by the beetle.

Results Abundance of terrestrial lichens (*Cladina* spp.) was low in salvaged blocks but similar to abundance in dead pine forests where it had decreased by 11.5% since 2006. Highest abundance was in 1990s clearcuts. Changes in vegetation cover indicate that dwarf shrubs are replacing litter in salvaged blocks and replacing Cladina spp., moss, and litter in the pine forest. Biomass of arboreal lichen in feeding areas remained constant through the study period. Comparison of snow conditions between clearcuts and dead pine forests indicate that pines were not effective at intercepting snow and encouraged softer snow. Note these results differ from other findings on snow interception (section 3.5.1). Caribou movement was associated with snow depth and hardness. During winter (2007–09), caribou used salvaged blocks, clearcuts, and pine forests on average 4, 18, and 77% of the time respectively. Caribou foraged in all three types of stands, but foraged exclusively in the pine forest when snow depth exceeded 50 cm. Caribou fed only on arboreal lichens when snow depth was > 45cm.

Gain in Knowledge During winter, use by caribou of salvage areas and clearcuts was similar. Despite the lack of needles, dead pine trees produced softer snow conditions that make it easier to crater in to reach lichens. Caribou were exclusively in the forested area when snow depth increased.

Sullivan, T. 2008. Stand structure and maintenance of biodiversity in green tree retention stands at 30 years after harvest: A vision into the future. FIA–FSP Project Y083008, Executive Summary. (see annotation in section 8.1.3)

Waterhouse, M. 2008. Silvicultural systems to maintain northern caribou habitat in lodgepole pine forests in central BC. FIA–FSP Project Y081133, Executive Summary. (see annotation in section 8.1.3)

Williston, P.; Cichowski, D. 2006. The response of caribou terrestrial forage lichens to forest harvesting and mountain pine beetles in the East Ootsa and Entiako areas. FIA–FSP Project Y061134, Final Report. (see annotation in section 8.1.3)

8.4 Landscape Issues and More General Studies

Cocksedge, W. 2008. Assessing cultural use species in mountain pine beetle affected areas. FIA–FSP Project Y082318, Executive Summary.

Purpose/Study Area To investigate the effects of mountain pine beetle on selected understorey plant and fungal species of cultural importance and priority to the T'exelc and Xats'ull First Nations. To date, the project links Predictive Ecosystem Mapping (PEM) units to plants of interest, but has no results associated with effects of pine beetle.

Methods July 2006 Project length: 3 years; former project number: FSP Y071318 (Yr 1)

Plants of interest: *Abies lasciocarpa, Amalanchier alnifola, Betula papyrifera, Juniperus communis, Ledum groenlandicum, Picea engelmannii x. glauca, Pseudotsuga menziesii, Shepherdia canadensis, Vaccinium caespitosum, Vaccinium ovalifolium, Vaccinium membranaceum, Vaccinium myrtilloides, Vaccinium ovalifolium, Vibernum edule/V. opulus*

Results No final results.

Gain in Knowledge The project links PEM to habitat for these species.

Goodwin, N.R.; Coops, N.C.; Wulder, M.A.; Gillanders, S.; Nelson, T. 2009. Determining year of death and nature of stand recovery using a time series analysis of remotely sensed data. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Technology Transfer Note 37.

Purpose/Study Area This report presents a procedure for characterizing beetle attack from multi-year Landsat Thematic Mapper (TM) satellite imagery. It includes a step-by-step summary of the actions needed to pre-process and then classify beetle attack.

Methods The authors present a methodology. To characterize beetle dynamics and link spectral changes to field data, it is advantageous to have pre-, during- and post-infestation monitoring data. Given the expense and time of field data collection, the authors note it is worthwhile to examine the history of image acquisition success (i.e., < 20% cloud cover) prior to field plot placement, because this can provide an indication of the difficulty in acquiring imagery due to cloud cover.

Results Emphasizes methods, with examples; not results of application.

Gain in Knowledge This note provides an overview of the key steps required to pre-process and extract information on mountain pine beetle dynamics using multiyear satellite data. Assuming annual cloud-free imagery is available, this approach can be used not only to classify the location(s) and area of insect attack, but also characterize its timing across forested landscapes.

Klenner, W. 2009b Landscape habitat supply modelling to develop and test management scenarios that balance ecological and socioeconomic indicators. FIA–FSP Y081282, Executive Summary.

Purpose/Study Area Uses a case study landscape of approximately 100 000 ha near Kamloops, BC, dominated by dry forest types to look at impacts of management and disturbances on desired characteristics.

Methods This 3-year project used multiple-scenario, habitat supply modelling to help identify practices that are likely to maintain desired conditions across large spatial and temporal scales (e.g., landscapes from 100–200 000+ ha and for periods of a century or more).

Results Not many expected until 2010. To date the project has focused on improving models.

Gain in Knowledge The landscape modelling shows that some desired conditions (e.g. old-growth management area targets or dispersion) are difficult or impossible to maintain in the face of non-equilibrium natural disturbances, and that specific management practices must be adopted to maintain options in dynamic ecosystems. Multiple-scenario landscape assessments can help identify unrealistic expectations, and illustrate the utility of specific stand (e.g., variable retention/partial cutting) and landscape management (e.g., aggregated harvesting, road deactivation) practices that favor achieving and maintaining desired conditions.

Morgan, D. 2008 A strategic analysis framework for managing forests under the mountain pine beetle outbreak. FIA–FSP M07-5025, Executive Summary.

Purpose/Study Area Study area is the Cranbrook TSA. The project has three main objectives;

1. provide an analytical framework to evaluate resource values and tradeoffs with explicit accounting for the uncertainty surrounding disturbance events, such as beetle outbreaks;
2. provide guidance to managers in addressing current beetle-affected landscapes based on evaluating data of a previous beetle infestation and forward-looking projections; and
3. project potential future increases in, and impacts of, development activities, such as recreation, grazing and harvest of non-timber forest products, that may result from increased road development associated with salvage harvesting of beetle-killed stands.

Methods Plausible scenarios of future landscape condition were constructed using the analytical framework. Landscape models were used to explore past and future landscape condition. Landscape modelling efforts from a range of projects were leveraged by linking to them and adapting their models. For example, for beetle projections, they downscaled results from the provincial beetle projection model. Landscape models were implemented using SELES (a Spatially Explicit Landscape Event Simulator). The late 1970s East Kootenay outbreak was characterized by creating electronic map layers of the pre-outbreak forest and road network conditions. Forest inventory information describing forest stand initiation and disturbance history was used to generate annual maps of the severity of bark beetle infestations, fire, and timber harvesting, reflecting past management response. A "roll back" model, built using SELES, was used to re-create the forest condition of 1973, prior to the 1970s outbreak. To generate a map of roads for 1973 the current road network was split into a set of segments. Starting in 1973, they projected landscape conditions forward to 2004 with an aim of exploring the range of possible outcomes and several scenarios:

- Historic logging: replays logging, fire, and mountain pine beetle to provide a simple baseline comparison and to verify that the model ends up with conditions close to 2004 conditions.
- No management: This scenario replays natural disturbance over this period, to provide a baseline of how the forest conditions may have developed in the absence of logging.
- Default management: applies the "status quo" management regime assumed in TSR 3 over this time frame, with an additional priority for salvage of disturbed stands.
- No salvage: the same as above, except no salvage was applied.
- Susceptibility focus: applied a priority to focus harvest as much as possible in susceptible stands, based on an approximation of the Shore and Safranyik beetle susceptibility rating. The scenario aims to quantify the degree to which susceptibility may have been reduced over this time frame.
- Minimize roads: harvests the same volume, but with a focus on minimizing road construction to access stands. The aim was to quantify the minimum amount of road that could have been built to harvest wood.

These scenarios were explored under a variety of assumptions:

- beetle outbreak ends or continues unabated;
- management applies no salvage, moderate salvage, or aggressive salvage;
- post-beetle, return to traditional forest management or use an alternative form of management;
- species recover as under historical climate, or climate change is mild or severe, leading to species conversion with change in ecological niches; and
- develop road access and potential associated developments over entire productive forest or delineate road-free areas and intensive management areas.

Results Results of scenarios were reported using several indicators: amount of road, amount of harvest, age of forest, forest extent, species habitat. They also considered climate change. Executive summary does not have details on results.

Gain in Knowledge Final report will present results.

O'Neill, G.; Berger, V.; Carlson, M.; Ukrainetz, N. 2009. Assisted migration adaptation trial FIA–FSP Projects 090138 (2008/09), 100238 (2009/10).

Purpose/Study Area This project seeks to understand the climate tolerances of BC's most important plantation species and seedlots by planting them across a wide climate range.

Methods 48 test sites will be established: 12 sites per year for 4 years. The first series of sites will be planted in spring 2009. Start-up funding (fiscal years 2006–07 and 2007–08) was provided by the Forest Genetics Council. Seedlots from 49 of the most widely planted seed orchard populations in BC and neighbouring states are being tested at 48 field sites across those regions. Productivity of each seedlot will be described as a function of site climate and latitude. Relationships used to develop an assisted migration seed deployment system are intended to increase the probability that plantations receive seedlots that will maximize plantation adaptation throughout the rotation.

Results None yet.

Gain in Knowledge It is anticipated that better understanding of species' climate tolerances can lead to developing seedlot deployment systems that optimize adaptation throughout the rotation.

Seely, B.; Nelson, J.; Vernier, P.; Wells, R.; Moy, A. 2008. Exploring opportunities for mitigating the ecological impacts of current and future mountain pine beetle outbreaks through improved planning: A focus on northeastern British Columbia. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2008-08.

Purpose/Study Area Authors conducted a scenario analysis designed to explore opportunities to mitigate the ecological and economic impacts of beetle salvage for two possible outbreak severity levels in Canfor's Tree Farm License (TFL) 48 in northeastern BC. The following questions were addressed:

- What are the potential short- and long-term impacts of different levels of beetle attack for indicators of sustainable forest management in northeastern BC?
- Assuming a reduction in landscape-level ecological and economic stocks, what management options are available that will maintain a profitable harvesting profile while sustaining ecological indicators?

Methods They modelled three scenarios (biodiversity emphasis, risk reduction, and production) using FORECAST, ATLAS, and SIMFOR. They also related bird abundance to habitat variables.

Results Scenarios suggest that at the landscape scale, with exception of pine-leading stand types, the impact of a high level of beetle attack on landscape-scale biodiversity indices was largely a byproduct of salvage harvesting and the associated shift in harvesting patterns required to maintain harvest levels following the salvage period.

At the stand level, beetle-attacked stands were projected to suffer varying losses of merchantable volume following attack depending on initial age class, pine content, and secondary species. Losses were greatest in mature stands (> 80 years old) with high pine content; however, even younger stands (age 40–80 years) showed long-term reductions in merchantable volume related to reduced stocking levels.

With respect to biodiversity indicators, beetle attack typically led to extended periods of time with few large snags following the loss of beetle-killed snags, particularly in stands with high initial pine content. Measures of large live structure were less impacted by the beetle as unsalvaged stands tended to retain enough large live stems to maintain the index at relatively high levels.

Long-term patterns of ecosystem carbon storage were affected by mountain pine beetle in a similar way to merchantable volume, but the relative impact of beetle attack was less pronounced because live biomass typically represents less than half of total carbon storage in these ecosystems. Results suggest that ecosystem carbon storage could be improved by as much as 20% over the long-term by salvaging and regenerating beetle-killed stands

Gain in Knowledge Comparison of the three salvage scenarios (Biodiversity—retention of live structure, Production—emphasis on reestablishment of productive pine dominant stands, and Risk Reduction—emphasis on a shift towards the re-establishment of spruce-dominated stands) yielded some interesting results. The Biodiversity option had the best overall performance. While it is not surprising that this option performed well with respect to the stand-level biodiversity indicators, it also performed reasonably well with respect to indices of merchantable volume, ecosystem carbon storage, and, surprisingly, beetle susceptibility. It even equaled or reduced the long-term susceptibility of most salvaged stand types compared to the Risk Reduction option. This related to retained non-pine species generally accounting for a substantial proportion of the basal area in the subsequent developing stand. Responses would differ where lodgepole was more abundant, but the importance of retaining non-pine species would be the same.

Shore, T.; Fall, A.; Burnett, C; and Riel, W.G. 2009. Characterization of the Jack pine forests of western Canada for susceptibitlity to infestation by the mountain pine beetle. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Working Paper 2009-04.

Purpose/Study Area Alberta and Saskatchewan.

Methods The project assesses provincial scale patterns and connectivity of mountain pine beetle-susceptible stands across Alberta and Saskatchewan using graph-based connectivity methods. The model SELES is used to create spatial graphs to assess connectivity between high susceptibility stands, as well as proximity across space to known infestations; it is applied across broad regions, under historic, existing or future climates.

Results The analyses suggest that western Alberta, especially in the Foothills and Smoky areas (north and east of Jasper and Willmore Wilderness) are fairly well connected, and post a high landscape-scale risk of MPB. Abundance and connectivity of hosts decreases as one moves east across the boreal forest of Alberta and into Saskatchewan.

Gain in Knowledge This information could help prioritize and rank stands for treatment in areas at risk of imminent or future infestation, and to identify areas for which treatment has no benefit.

Steventon, D. 2008. Landscape strategies for mountain pine beetle management: Some stewardship implications. FIA–FSP M075006, Executive Summary.

Purpose/Study Area Researchers used literature review and modelling to examine wildlife stewardship implications of management strategies for the mountain pine beetle outbreak. The Nadina Forest District was the test landscape.

Methods There was a prior project, Y062053. Potential future landscape conditions were projected under a variety of management scenarios (> 128 combinations to date). Scenario variables include harvest rate schedule, harvest selectivity (in terms of salvaging lodgepole pine and avoiding salvage of stands with significant understorey), protection of understorey during

harvesting, wildlife tree patch retention levels, regeneration delay and beetle-kill shelf life assumptions, application of landscape seral-stage constraints, and application of fixed reserves and corridors. Stochastic natural disturbance was applied, as potentially affected by climate change, to a subset of the basic management scenarios.

The landscape scenarios were first evaluated using a number of general sustainability indicators (e.g., abundance of mature and old forest), and a subset of the scenarios was further evaluated using the detailed habitat quality/abundance, home-range delineation, and dispersal connectivity models for several "species" profiles. Assessing the value of maintaining "secondary structure" (non-pine overstorey and understorey) is a pressing management issue. Thus for more detailed assessment they applied the species models to three priority scenarios:

1. salvage emphasis on dead pine and high-risk live pine (maximum 10% of harvest from non-pine species) along with maximal protection of understorey by salvage avoidance and full preservation during subsequent harvesting;
2. salvage emphasis on pine but harvesting other species if necessary, while avoiding and preserving understorey; and
3. the same as (2) but without avoiding or preserving understorey.

Results They provide an example of marten habitat under different scenarios.

Gain in Knowledge The executive summary provides insufficient data to permit evaluation.

Steventon, D. 2009. Landscape strategies for mountain pine beetle management: Some stewardship implications. FIA–FSP M086006, Executive summary.

Purpose/Study Area Bunnell et al. (2004) provided a review of mostly stand-level approaches, but did not address the landscape scale in detail. Eng (2004) reviewed both stand- and landscape-scale stewardship principles but did not conduct any assessment of feasibility, and Klenner (2006) provided salvage harvesting guidelines at the stand level. This project builds on those reviews, "testing" some of the management principles through simulation modelling of the ~ 2.6 million ha Nadina Forest District. The intent is to assess how to conduct harvesting in a way that best achieves wildlife stewardship goals given the large increase in salvage harvesting.

Methods The project ran from 2006 to 2008. They used spatially explicit landscape simulations combined with habitat and population modelling to assess management strategies for a sub-boreal landscape (Nadina Forest District) subject to an extensive beetle outbreak and climate change. A shortlist of management options considered for detailed examination was: protection of understorey trees during logging, 30 to 70% retention of overstorey (partial cutting) for 30 or 50% of the area harvested each year, and timber harvest rate (100, 80, or 50% of current long-term sustained harvest estimates).

Results No results—there does not appear to be a technical report yet.

Gain in Knowledge This project is just beginning. They anticipate outcomes will improve local Ungulate Winter Range (UWR) management and aid the persistence of caribou populations by:

- distinguishing UWRs that require active management from those that do not;
- specifying management options for sites requiring active disturbance;
- improving the understanding of regional differences in UWR ecology; and
- improving the understanding of the likely response of caribou to beetle-attacked range.

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